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**Resistibility tests for telecommunication
equipment exposed to overvoltages and
overcurrents – Basic Recommendation**

Recommendation ITU-T K.44



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Resistibility tests for telecommunication equipment exposed to overvoltages and overcurrents – Basic Recommendation

Summary

Recommendation ITU-T K.44 seeks to establish fundamental test methods and criteria for the resistibility of telecommunication equipment to overvoltages and overcurrents.

Overvoltages or overcurrents covered by this Recommendation include surges due to lightning on or near the line plant, short-term induction of alternating voltages from adjacent electric power lines or electrified railway systems, earth potential rise due to power faults, and direct contacts between telecommunication lines and power lines.

Major changes compared with the 2003 version of this Recommendation include:

- the addition of substantial information and schematics relating to decoupling, terminating and coupling to ground of associated equipment;
- the introduction of an internal port to internal port test;
- information on classifying ports as external or internal;
- the addition of tolerances for the power induction and power contact tests;
- criterion A has been modified.

Source

Recommendation ITU-T K.44 was approved on 13 April 2008 by ITU-T Study Group 5 (2005-2008) under Recommendation ITU-T A.8 procedure.

FOREWORD

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NOTE

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Recommendation ITU-T K.44

Resistibility tests for telecommunication equipment exposed to overvoltages and overcurrents – Basic Recommendation

1 Scope

This basic Recommendation describes resistibility tests for all telecommunication equipment against overvoltages and overcurrents for use by network operators and manufacturers.

This Recommendation applies to all telecommunication equipment connected to external or intra-building metallic conductors. It should be read in conjunction with [ITU-T K.11] and [ITU-T K.39] which deal with the general economic and technical aspects of protection.

This Recommendation does not specify either test levels or particular acceptance criteria for specific equipment.

The appropriate test levels and test points are contained in the specific product family or product Recommendation.

Therefore, this Recommendation has to be used together with the product family or product Recommendation dealing with the resistibility requirements relevant to the equipment to be tested.

If a product family or product Recommendation or clause of it differs from this basic Recommendation, the product family or product Recommendation applies. As product Recommendations are updated, they should be coordinated with and refer to this Recommendation.

This Recommendation assumes that the earthing and bonding configurations comply with the appropriate Recommendation related to the type of installation.

The tests are type tests and, although they are applicable to a complete system, it is recognized that they may be applied to individual items of equipment during development and design work. In performing the tests, it is necessary to take into account any conditions, either in the unit under test or elsewhere, which may affect the results.

ESD testing is not covered by this Recommendation and [IEC 61000-4-2] should be followed.

2 References

The following ITU-T Recommendations and other references contain provisions which, through reference in this text, constitute provisions of this Recommendation. At the time of publication, the editions indicated were valid. All Recommendations and other references are subject to revision; users of this Recommendation are therefore encouraged to investigate the possibility of applying the most recent edition of the Recommendations and other references listed below. A list of the currently valid ITU-T Recommendations is regularly published. The reference to a document within this Recommendation does not give it, as a stand-alone document, the status of a Recommendation.

[ITU-T K.11] Recommendation ITU-T K.11 (1993), *Principles of protection against overvoltages and overcurrents*.

[ITU-T K.12] Recommendation ITU-T K.12 (2000), *Characteristics of gas discharge tubes for the protection of telecommunications installations*.

[ITU-T K.20] Recommendation ITU-T K.20 (2008), *Resistibility of telecommunication equipment installed in a telecommunication centre to overvoltages and overcurrents*.

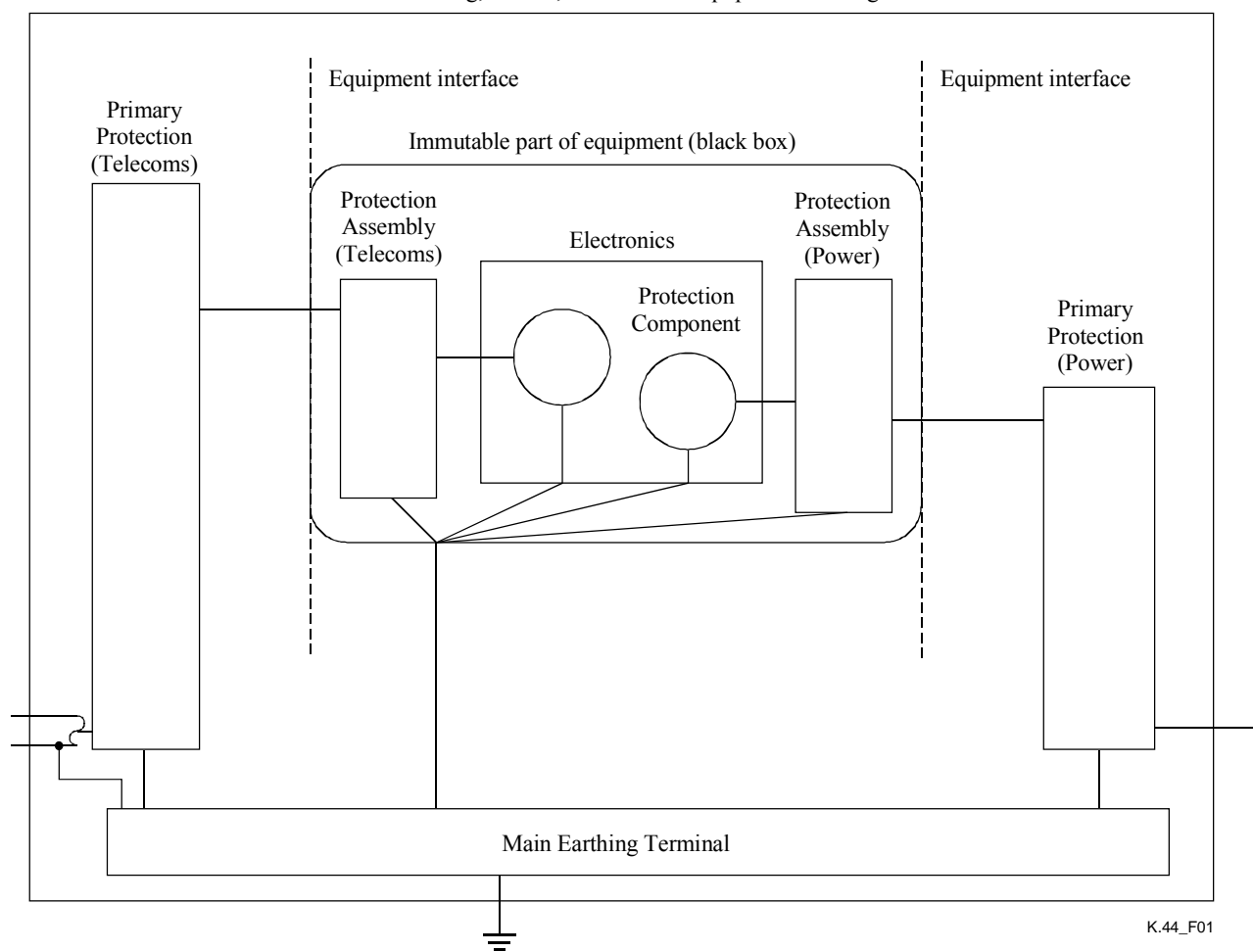
[ITU-T K.21] Recommendation ITU-T K.21 (2008), *Resistibility of telecommunication equipment installed in customer premises to overvoltages and overcurrents*.

- [ITU-T K.27] Recommendation ITU-T K.27 (1996), *Bonding configurations and earthing inside a telecommunication building.*
- [ITU-T K.28] Recommendation ITU-T K.28 (1993), *Characteristics of semi-conductor arrester assemblies for the protection of telecommunications installations.*
- [ITU-T K.30] Recommendation ITU-T K.30 (2004), *Self-restoring overcurrent protectors.*
- [ITU-T K.39] Recommendation ITU-T K.39 (1996), *Risk assessment of damages to telecommunication sites due to lightning discharges.*
- [ITU-T K.45] Recommendation ITU-T K.45 (2008), *Resistibility of telecommunication equipment installed in the access and trunk networks to overvoltages and overcurrents.*
- [IEC 60060-1] IEC 60060-1 (1989), *High-voltage test techniques. Part 1: General definitions and test requirements.*
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- [IEC 61000-4-2] IEC 61000-4-2 (2001), *Electromagnetic compatibility (EMC) – Part 4-2: Testing and measurement techniques – Electrostatic discharge immunity test.*
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- [IEC 61000-4-5] IEC 61000-4-5 (2005), *Electromagnetic compatibility (EMC) – Part 4-5: Testing and measurement techniques – Surge immunity test.*
<<http://webstore.iec.ch/webstore/webstore.nsf/artnum/035289>>
- [IEC 61643-1] IEC 61643-1 (2002), *Low-voltage surge protective devices – Part 12: Surge protective devices connected to low-voltage power distribution systems – Selection and application principles.*
<<http://webstore.iec.ch/webstore/webstore.nsf/artnum/028546>>

3 Definitions and abbreviations

3.1 Definitions

To assist in understanding the various definitions, refer to Figure 1. This figure shows elements associated with protecting the equipment that may be in an installation. Not all of these elements are expected to be used in an installation.



NOTE – The arrangement of the blocks and bonding conductors inside of the building, shelter, structure or equipment housing is to assist in their identification and does not infer an optimum physical arrangement from a protection point of view.

Figure 1 – Illustration of protection elements

This Recommendation defines the following terms:

3.1.1 access network (AN): That part of the overall telecommunication network that is located between a telecommunication centre and the customer premises building.

3.1.2 agreed primary protection: An agreed primary protector is the type of SPD that will be used to protect the equipment. An agreed primary protector may be a specific SPD or a range of SPDs which comply with a particular Recommendation, standard or specification. The agreed primary protector is often specified by the network operator, but it may be the result of discussions between the network operator and the equipment manufacturer. The agreed primary protector can be nothing if it has been agreed that no external protection elements need to be used for the equipment.

3.1.3 coupling element: A coupling element is a low impedance component, under surge conditions, used to connect the surge generator to the port being tested or to couple an untested port to ground.

3.1.4 customer premises equipment (CPE): Equipment intended to be directly connected to the termination of a public telecommunication network in a customer's premises.

3.1.5 decoupling element: A decoupling element is a component with a suitable impedance to reduce the level of energy being conducted into auxiliary equipment or terminations.

3.1.6 dedicated power feed (dpf): A dedicated power feed is a power feed provided by a dedicated telecommunications cable which leaves the building and is used exclusively to provide the power feed. See "remote power feed".

3.1.7 external cable termination point: The point where the external cable terminates and connects to the building cabling.

NOTE – This is also the point where SPDs would be installed, if required.

3.1.8 foldback protection device: This clamping-type voltage limiter utilizes transistor action to create a re-entrant or "foldback" characteristic.

3.1.9 high current carrying protection components: A high current carrying protection component is an SPD which, when activated by the surge, conducts/diverts the majority of the surge away from the circuit it is protecting. High current carrying protection components are mainly used as primary protection components, but in some cases may be integrated into the equipment as inherent protection.

3.1.10 IT power distribution system: An IT power system is isolated from earth, except that one point may be connected to earth through an impedance or a voltage limiter. The parts of the equipment to be earthed are connected to earth electrodes at the user premises.

3.1.11 inherent protection: Inherent protection is that protection which is provided at an equipment interface either by virtue of its intrinsic characteristics, by specific design, or by suitable protection components.

3.1.12 primary protection: Primary protection is applied using an SPD to protect an interface of the equipment at the location where it diverts most of the stressful energy from propagation into the equipment. This SPD must be accessible, removable and connected to equipotential bonding.

3.1.13 protection coordination: The act of ensuring that all protection elements, internal and external to the equipment, react in such a way so as to limit the amount of energy, voltage or current to levels such that damage does not occur to protection elements or equipment.

3.1.14 Interface ports

3.1.14.1 external port: An external port is any interface on the equipment which may be subjected to a.c. surges and lightning surges conducted from an outdoor cable.

NOTE – Clause A.2.1 provides guidance on classification of ports.

3.1.14.1.1 coaxial cable port: The port connects to a coaxial cable.

3.1.14.1.2 dedicated power feed port: The port connects to a dedicated power feed cable.

3.1.14.1.3 mains power port: The port connects to a cable which provides mains power.

3.1.14.1.4 symmetric pair port: The port connects to a cable with metallic symmetric conductors (see [ITU-T K.46]). The cable may be shielded or non shielded.

3.1.14.2 internal port: An internal port is any interface on the equipment which is only ever subjected to short duration induced transients, due to induction into building wiring.

NOTE – Clause A.2.1 provides guidance on classification of ports.

3.1.14.2.1 d.c. power interface ports: The port connects to a cable, e.g., a shielded cable which provides d.c., power e.g., –48 V.

3.1.14.2.2 shielded cable port: The port connects to a shielded cable including a coaxial cable.

3.1.14.2.3 unshielded cable port: The port connects to an unshielded cable.

3.1.14.3 intra-system port: A port used for interconnecting equipment modules of the same system within a building. The interconnecting cabling is under the control of the equipment manufacturer.

3.1.15 positive temperature coefficient thermistor (PTC): Thermistor in which the resistance increases with increasing temperature throughout the useful part of its characteristic. The PTC thermistors covered in this Recommendation typically exhibit a very sharp increase in resistance over a narrow temperature range

3.1.16 remote power feed: A remote power feed is a power feed provided by symmetric signal pairs or inner conductors of coaxial circuits simultaneously used for signal transmission. An example of a remote power feed is a remote feed telecommunication (RFT). Remote power feeds complying with the requirements for a TNV circuit are not classified as a remote power feed. The requirements for a TNV circuit are provided in [b-IEC 60950-1], a dedicated power feed (dpf) is defined in clause 3.1.6, and an RFT is defined in [b-ITU-T K.50].

3.1.17 resistibility: Resistibility is the ability of telecommunication equipment or installations to withstand, in general, without damage, the effects of overvoltages or overcurrents, up to a certain specified extent, and in accordance with a specified criterion.

NOTE – Resistibility is considered to cater for the needs of the whole of the telecommunication network, i.e., all types of networks, public and private, as well as any equipment installed in or connected to this network. The resistibility requirements are based on the following electromagnetic phenomena: lightning, power induction, earth potential rise and low-voltage power contact.

3.1.18 special test protector: The special test protector is a component or circuit used to replace the agreed primary protector for the purposes of confirming coordination. The special test protector limiting characteristics ensure that the voltage and current levels at the input of the equipment will be higher during the test than in service and provides a level of guarantee that the equipment will be protected by the addition of primary protection.

3.1.19 surge protective device (SPD): Device that restricts the voltage of a designated port or ports, caused by a surge, when it exceeds a predetermined level:

- 1) Secondary functions may be incorporated, such as a current-limiting device to restrict a terminal current.
- 2) Typically, the protective circuit has at least one non-linear voltage-limiting surge protective component.
- 3) An SPD is a combination of a protection circuit and holder.

3.1.20 telecommunication centre: A telecommunication centre is a telecommunication facility where the earthing and bonding is in accordance with [ITU-T K.27].

3.1.21 telecommunication network: A transmission medium intended for communication between equipments that may be located in separate buildings.

NOTE 1 – The term telecommunication network is defined in terms of its functionality, not its electrical characteristics.

NOTE 2 – A telecommunication network may be:

- publicly or privately owned;
- subject to transient overvoltages due to atmospheric discharges and faults in power distribution systems;
- subject to permanent longitudinal (common mode) voltages induced from nearby power lines or electric traction lines.

NOTE 3 – Examples of telecommunication networks are:

- public switched telephone network (PSTN);
- next generation network (NGN);
- public data network;
- a private network with electrical interface characteristics similar to the above.

3.1.22 termination component: A termination component is a component used to simulate the connection of auxiliary equipment to a tested or untested port.

3.1.23 thermistor: Thermally sensitive semiconducting resistor whose primary function is to exhibit an important change in electrical resistance with a change in body temperature.

3.1.24 trunk network (TNW): That part of the telecommunication network that is located between two telecommunication centres that provides the communication between the centres.

3.1.25 TT power distribution system: A TT power distribution system has one point directly earthed, the parts of the equipment required to be earthed being connected at the user premises to earth electrodes that are electrically independent of the earth electrodes of the power distribution system.

3.2 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

a.c.	alternating current
AE	Auxiliary Equipment
AN	Access Network
ANE	Access Network Equipment
BN	Bonding Network
CBN	Common Bonding Network
CPE	Customer Premises Equipment
d.c.	direct current
dpf	dedicated power feed
ECTP	External Cable Termination Point
EPR	Earth Potential Rise
ESD	ElectroStatic Discharge
EUT	Equipment Under Test
GDT	Gas Discharge Tube
IBN	Isolated Bonding Network
ISDN	Integrated Services Digital Network
LE	Local Exchange
LI	Line Interface
LT	Line Termination
MDF	Main Distribution Frame
MOV	Metal Oxide Varistor
n.a.	not applicable
NT	Network Termination
o/c	open circuit
pfv	power feeding voltage
PTC	Positive Temperature Coefficient thermistor

ROEP	Rise of Earth Potential
RSE	Remote Switching Equipment
SOP	Semiconductor Overcurrent Protector
SPD	Surge Protective Device
SSA	Solid State Arrester
TCE	Telecommunication Centre Equipment
TDD	Time Division Duplex
TNV	Telecommunication Network Voltage
TNW	Trunk NetWork
USB	Universal Serial Bus

3.3 Symbols

This Recommendation uses the following symbols:

U_c	d.c. charge voltage of the surge generator.
$U_{c(max)}$	Maximum d.c. charge voltage of the surge generator.
$U_{a.c.(max)}$	Maximum a.c. (open) voltage for the a.c. voltage tests.

4 Overvoltage and overcurrent conditions

Aspects of overvoltage or overcurrent covered by this Recommendation are:

- surges due to lightning strokes on or near to the line plant;
- large currents in common wiring or components when overvoltages or overcurrents occur simultaneously on a number of lines;
- large currents flowing into the equipment when high current carrying protection components, which eliminate the need for primary protection, are integral to the equipment;
- short-term induction of alternating voltages from adjacent electric power lines or electrified railway systems, usually when these lines or systems develop faults;
- earth potential rise due to power faults;
- direct contacts between telecommunication lines and mains power lines;
- transient surges on mains-voltage lines;
- the potential difference which can occur between a TT or IT power system and the telecommunication system.

5 Resistibility requirements

Telecommunication lines, remote (dedicated) power feeding lines and mains power lines are more or less influenced in the practical environment by lightning or power lines. The several degrees of influence and protection measures are described in [ITU-T K.11]. With reference to the resistibility of telecommunication equipment connected to metallic conductors, there may be different resistibility requirements in different environments. It is for administrations or network operators to select the appropriate resistibility requirement from the product family or product Recommendations. In the interest of reducing the number of equipment designs, only the basic and enhanced requirements are recommended in the product Recommendations at this point in time.

Examples of when "enhanced" resistibility levels may be required are:

- The I²t of power induction and EPR surges exceed 1 A²s.
- Mains primary protector SPDs are not normally installed. Note that where mains primary protector SPDs cannot be installed, "special" requirements may be required, see below.
- Equipotential bonding at customer premises is difficult to achieve, e.g., the bond wire is greater than a few metres. Note that where bonding between the mains and telecommunications cannot be achieved, "special" requirements may be required, see below.
- Customer equipment has more than one telecommunications port, e.g., telecommunications plus mains.

While the product Recommendations do not provide special resistibility requirements, it is acknowledged that special conditions can exist where even the enhanced resistibility requirements are not sufficient. An example of this is where primary protection cannot be installed in the main a.c. service cabinet for some technical or regulatory reason. In this case, the network operator may need to request special resistibility requirements. Some guidance and possible test levels are provided in clause II.6.

5.1 Basic resistibility requirement

The equipment needs to be suitable for use in environments with a lower exposure, and this is achieved by the inherent protection of the equipment. The equipment also needs to be suitable for use in environments with a higher exposure, and this is achieved by inherent protection of the equipment and added agreed primary protection.

5.2 Enhanced resistibility requirement

Where the basic resistibility requirements are not sufficient due to environmental conditions, national regulations, economic and technical considerations, installation standards or grade of service requirements, network operators may request the enhanced resistibility requirement.

6 Equipment boundary

The variations of different types of equipment make it necessary for the equipment to be seen as a "black-box" having several ports, a, b, c, d, e and f, etc., and E (earth). It is possible that some protective devices have already been provided in the equipment, either on the printed circuit board, etc., or connected to its ports. For the purpose of these tests, manufacturers are expected to define the boundaries of the "black-box" and any protective device which is included must be considered as an immutable part of the equipment (small exchange in street cabinet, multiplexer, CPE, etc.). Where high current carrying protection components are used within the equipment, see clause 10.1.1. Where any auxiliary telecommunication wire is provided, e.g., to an extension or as a signalling earth, these wires should be seen to extend the number of terminals to be tested, e.g., a, b, c, d, e and f, etc., and E for earth.

7 Test conditions

7.1 Port types

There are three types of ports, external, internal and intra-system.

The external port types are:

- 1) Symmetric pair.
- 2) Coaxial cable.

- 3) Dedicated power feed.
- 4) a.c. mains power.

The internal port types are:

- 1) Unshielded cable, including symmetric and asymmetric pair unshielded cables.
- 2) Shielded cable including symmetric and asymmetric pair shielded cables and coaxial cables.
- 3) Floating d.c. power.
- 4) Earthed d.c. power.

Intra-system ports are expected to be interconnected by short cables or shielded cables (cable screen or cable trays, etc.) under the control of the manufacturer. As these types of ports are not normally exposed to damaging overvoltages, requirements have not been specified.

7.2 Test types

Up to six types of test need to be performed on equipment, depending on the port type and equipment earthing. These tests are:

- transverse (line to line);
- external port to earth;
- external port to external port;
- external port to internal port. Note that this test is performed as part of the external port to earth test;
- internal port to earth;
- internal port to internal port. Note that this test is performed as part of the internal port to earth test.

7.2.1 Transverse/differential

A transverse or differential test should be performed on all external port types of the equipment. The test is performed with some untested ports of each port type terminated.

7.2.2 External port to earth

External port to earth tests should be performed on all equipment with external ports. This test is performed with all untested ports (both internal and external) terminated and then repeated with each type of internal port, earthed via a coupling element, in turn.

7.2.3 External port to external port

External port to external port tests should be performed on equipment with more than one external port. When the equipment is designed to be used with a connection to ground, the product Recommendation specifies when the test is to be performed. This test is performed with all untested ports (both internal and external) terminated, with each type of external port, including a port of the same type, grounded via a coupling element, in turn.

It is necessary in external port to external port testing to consider the following as the second port:

- 1) other lines/pairs of the port type being tested (e.g., pair 1 to pair 2 of port type 1);
- 2) lines/pairs of other port types (e.g., pair 1 of port type 1 to pair 1 of port type 2).

An example of a test sequence is provided in Figure 2.

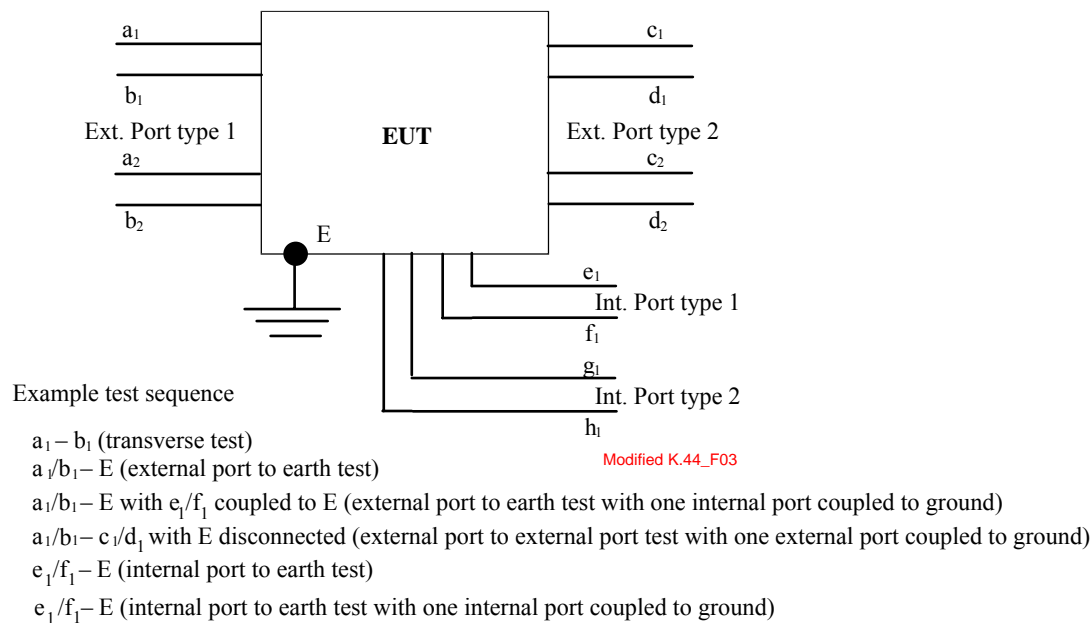


Figure 2 – Example of a test sequence

7.2.4 Internal port to earth

Internal port to earth tests are performed on all internal port types classified as an internal port (see clause A.2.1), unless excluded by the product Recommendation. This test is performed with some untested ports of each port type terminated and then with each type of internal port coupled to ground in turn.

7.3 Test conditions

The following conditions apply to all the tests specified in clause 10.

- 1) All tests are type tests and are tested under standard operating conditions unless otherwise specified in the product family or product Recommendation.
- 2) The ports at which tests on the equipment are to be applied should be identified by the manufacturer:
 - a and b , c and d , e and f , etc., for different single symmetric pair ports;
 - a_1 to a_n and b_1 to b_n , c_1 to c_m and d_1 to d_m , e_1 to e_p and f_1 to f_p , etc., for different multiple symmetric pair ports;
 - inner and outer for coaxial cable ports;
 - dpf_1 and dpf_2 , etc., for dedicated power feed ports;
 - L_1 , L_2 , L_3 and N for mains power ports; and
 - E for earth.
- 3) Tests shall be performed with the equipment operating, the only exception to this is during the power contact test. Note that if the power contact test is performed without the equipment being powered, it must not affect the test result. The equipment shall be tested in any operating state of significant duration, see clause A.2.4. To prove compliance, the equipment may need to be tested with both the tested and untested ports terminated, and with untested ports coupled to ground, see clauses A.5 and I.1.5.

- 4) Terminations for the tested and untested ports include auxiliary equipment, e.g., LI, LT, NT, CPE, a power supply, a simulator or a passive termination. If it is not necessary to have the auxiliary equipment connected in order to verify that the EUT will resist the test voltage, the test may be performed without the auxiliary equipment connected. Where different terminations may occur, e.g., with or without primary protection, these terminations need to be considered, refer to clause I.1.5. Decoupling elements are used to prevent the surge damaging the auxiliary equipment or termination.
- 5) Ports may need to be tested with a finite number of untested ports of the same and different types grounded in order to confirm that the equipment fulfils the specified acceptance criteria. Coupling elements are used to ground the appropriate port as required in 7 and 8 below.
- 6) Transverse tests shall be performed with at least one port of each type of port terminated.
- 7) External port to earth tests shall be performed without coupling to ground on the untested ports and also with each type of internal port coupled to ground in turn.
- 8) External port to external port tests shall be performed with each type of external port, including a port of the same type, coupled to ground in turn.
- 9) Each test shall be applied the number of times indicated in the product family or product Recommendation. The polarity of lightning surge tests should be reversed between consecutive surges. The time interval between consecutive tests on the same port should be approximately one minute. The tests shall also be applied at longer time intervals, if necessary, to confirm that the equipment fulfils the specified acceptance criteria for surges which occur at intervals exceeding one minute. An example of this is to confirm that the equipment passes when all surges are applied to PTCs at normal operating temperature.
- 10) When the transverse test is applied between two terminals, one of the terminals shall be connected to the surge generator and the other terminal shall be connected to earth. The test shall then be repeated with the terminals transposed.
- 11) Power induction tests should be made at the frequencies of the electric power system or the electrified railway systems used in the country of application.
- 12) In all cases where a maximum voltage, current or I^2t is specified, tests shall also be made at lower values to confirm that the equipment fulfils the specified acceptance criteria for any voltage, current or I^2t up to the maximum value specified. Confirming that the equipment complies with the requirements at voltages less than $U_{c(max)}$ can be performed using either of the two methods which are described below:
 - Using a knowledge of the protection elements. Clause I.1 gives an example of how to perform lightning and power induction tests at specific test points to ensure that the equipment complies with the requirements of the product Recommendation. Where the tests are only performed at maximum values, the reason shall be given in the test report, e.g., the equipment does not contain switching type secondary protectors.
 - Using set test levels as described in [b-IEC 61643-21]. If this method is used, tests shall be performed at 20%, 30%, 45%, 60%, 75%, 90% and 100% of $U_{c(max)}$.

Where product Recommendations allow reduced testing, e.g., power contact tests, as many tests as necessary shall be performed in order to confirm that the equipment fulfils the specified acceptance criteria.

NOTE – Particular components which need to be considered during testing include the primary protector, switching or foldback type inherent protectors, PTCs and fuses.

Where fuse resistors are used, tests shall be applied at a range of test levels to ensure that the worst case is tested.

- 13) A new primary protection component (special test protector or agreed primary protector) may be used if degradation of the protector is thought to, or known to, have occurred.
- 14) Where components may have significant variations in characteristics which can affect the resistibility level of the equipment, e.g., PTCs where their cold resistance could vary from, for example, 2-7 Ω , tests should be performed on equipment using the worst case component or by using any other method which achieves the aim. A worst case component is one which causes the equipment to have the lowest resistibility level.
- 15) Cards shall be tested in one or more slots as is necessary to confirm that the equipment fulfils the specified acceptance criteria.
- 16) If a card has two or more identical ports, only one port needs to be tested for single port tests.

7.4 Test schematics

Refer to Annex A.

8 Protection coordination

8.1 General

For equipment installed in a more exposed environment, it is current practice to protect ports, connected to external metallic conductors, with primary protectors such as GDTs, SSAs or MOVs. The best place for the insertion of the primary protection is the border of the building, shelter or equipment housing. This is not always possible but every attempt should be made to place the primary protection as close as possible to the entry point of the cables into the building, shelter or equipment housing. The characteristics of these primary SPDs shall comply with the requirements of [ITU-T K.12], [ITU-T K.28] or [IEC 61643-1].

Primary protection coordination is required to ensure compatibility of the equipment with the primary protection.

8.2 Lightning

To achieve coordination for protection against lightning surges, the following must occur:

- The inherent protection within the equipment must provide protection up to the voltage at which the agreed primary protection operates for generator voltages less than the $U_{c(max)}$ specified in the product family or product Recommendation.
- Between this voltage and a generator voltage of $U_{c(max)}$, the primary protection must operate and protect the equipment.
- The equipment must comply with the specified criterion of the product family or product Recommendation.
- The lightning surge coordination tests use a special test protector (see clause 8.4), instead of the primary protector, to allow the use of a safety factor during the tests. This safety factor includes: the maximum primary protector voltage, tolerances on equipment components, the number of test samples and the effect of multiple impulses. At a generator voltage setting equal to the $U_{c(max)}$ of the product family or product Recommendation, the special test protector must operate. The special test protector may of course also operate at values less than $U_{c(max)}$.

8.2.1 Primary SPDs with a switching characteristic

Coordination is achieved with a switching type SPD when the special test protector (see clause 8.4.1) is activated with a U_c below the maximum level specified in the relevant product family or product Recommendation, for testing with agreed primary protection, and the equipment complies with the specified criterion of that Recommendation.

8.2.2 Primary SPDs with a clamping characteristic

Coordination with a clamping type SPD is achieved when the equipment complies with specified criterion of the product Recommendation when tested with the special test protector (see clause 8.4.2), when tested at the maximum test voltage and current of the coordination test, i.e., when the primary SPD is conducting maximum current.

8.3 Power induction, earth potential rise and power contact

Protection against power induction and EPR, as a result of a power fault to ground, is achieved by the inherent protection within the equipment or in combination with the agreed primary protection.

Protection against power contacts is achieved by the inherent protection of the equipment.

The input impedance to ground of both the a and b inputs of some equipment may be low when the inherent overvoltage protection is activated. In this case, the voltage across the impedance to ground, caused by the current that flows during power induction or EPR, may be too low to activate the primary protection. If the primary protection is not activated, attention should be paid to the level of energy which may have to be dissipated within the equipment.

8.4 Special test protector

The special test protector shall have similar behaviour to that of the agreed primary protector.

8.4.1 Switching type protector

The d.c. operating voltage of the special test protector shall be equal to 1.15 times the specified maximum d.c. operating voltage, after life test value, of the agreed primary protector. The tolerance of this firing voltage is $\pm 5\%$. It should also have a similar impulse to d.c. operating ratio as the agreed primary protector. The manufacturer may use a special test protector with a higher operating voltage.

8.4.2 Clamping type protector

The clamping voltage of the special test protector shall be equal to 1.15 times the specified maximum clamping voltage of the agreed primary protector. The tolerance of this clamping voltage is $\pm 5\%$. The manufacturer may use a special test protector with a higher operating voltage.

8.4.3 Multistage modules

When the primary protection is a multistage module, replace the primary protection with a special test module which uses components according to clauses 8.4.1 and 8.4.2.

8.5 Selection of the agreed primary protector

A test house or laboratory needs to be given the characteristics of the "agreed" primary protector for the equipment under test so that they can select the special test protector. Information on how to select the "agreed" primary protector for GDTs is contained in [ITU-T K.12].

9 Acceptance criteria

Two acceptance criteria are recognized:

- Criterion A equipment shall withstand the test without damage and shall operate within the specified performance limits after the test without manual intervention.

NOTE – No manual intervention means that the equipment shall self-recover without any actions of the customer or service personnel. It is acceptable for the tested port and auxiliary equipment operation to be disrupted and outside specified performance limits during the test period and for any protection self-recovery time. The port test shall not affect the continuous operation of other hardware or software parts of the equipment under test.

- Criterion B – The tests shall not result in a fire hazard in the equipment; in particular:
 - if a fire occurs, it shall not propagate beyond the equipment; and
 - the equipment shall not emit molten metal.

Any damage, if it occurs, shall be confined to a small part of the equipment.

10 Tests

The test generators, test circuits, coupling and decoupling elements, and port terminations are provided in Annex A.

Certain considerations which justify the test proposals are stated in Appendix I. The response of equipment to surges may be modified by the input impedance of the equipment. To explain this effect, Appendix I includes an example circuit and instantaneous levels of voltage at different points in the circuit to show the effect of input impedance. These values are included for illustration only and do not form any part of this Recommendation.

The port types shown in Table 1 are considered. Remote power feeds share the same port as the signal port.

Table 1 – Port types

Port type		Test type	Example
External	Symmetric pair	Lightning	Analogue customer interface ISDN basic-rate interface Remote power feeding circuits xDSL interface
		Power induction and earth potential rise	
		Mains power contact	
	Coaxial cable	Lightning	ISDN primary-rate interface Remote power feeding circuits
		Power induction and earth potential rise	
	Dedicated power feed (a.c., d.c.)	Lightning	Optical network unit/termination power feed interface
		Power induction and earth potential rise	
	a.c. mains power	Lightning	a.c. mains power
		Earth potential rise and neutral potential rise	
Internal	Unshielded cable	Lightning	
	Shielded cable (including coaxial cable)	Lightning	
	d.c. power interface	Lightning	

A summary of the applicable tests is given in Table 2. The numbers given in the "port type" columns, e.g., 10.1.2, refer to the appropriate clause number in this Recommendation which discusses this test. The letters "n.a." mean the test is not applicable. The words "under study" mean that ITU-T is still studying this test. The terms "single" and "multiple" refer to the number of ports tested. For a single port test, the test is applied to one port only. For a multiple port test, the surge is applied to the number of ports specified simultaneously. The terms "transverse", "port to earth" or "port to external port" refer to whether the surge is applied transversely (i.e., line to line, line to shield, or in differential mode), port to earth (line to ground or in common mode) or port to external port (port to port with the earth reference floating).

Table 2a – Applicable tests for external ports

Test type	Number of ports simultaneously tested	Test mode	Primary protection	Port type			
				Symmetric port	Coaxial port	Dedicated power feed port	Mains power port
Lightning voltage	Single	Transverse	No	10.1.1.1	Under study	10.3.1	10.4.1
		Port to earth	No	10.1.1.1		10.3.1	10.4.1
		Port to external port	No	10.1.1.1		10.3.1	10.4.1
		Transverse	Yes	10.1.1.1		10.3.1	10.4.1
		Port to earth	Yes	10.1.1.1		10.3.1	10.4.1
		Port to external port	Yes	10.1.1.1		10.3.1	10.4.1
	Multiple	Port to earth	No	10.1.1.2		n.a.	n.a.
		Port to external port	No	10.1.1.2		n.a.	n.a.
		Port to earth	Yes	10.1.1.2		n.a.	n.a.
		Port to external port	Yes	10.1.1.2		n.a.	n.a.

Table 2a – Applicable tests for external ports

Test type	Number of ports simultaneously tested	Test mode	Primary protection	Port type			
				Symmetric port	Coaxial port	Dedicated power feed port	Mains power port
Lightning current	Single	Transverse/differential	No	n.a.	Under study	n.a.	n.a.
		Port to earth	No	10.1.2		10.3.2	n.a.
		Port to external port	No	10.1.2		10.3.2	n.a.
		Transverse	Yes	n.a.		n.a.	n.a.
		Port to earth	Yes	n.a.		n.a.	n.a.
		Port to external port	Yes	n.a.		n.a.	n.a.
	Multiple	Port to earth	No	10.1.2		n.a.	n.a.
		Port to external port	No	10.1.2		n.a.	n.a.
Power induction and earth potential rise	Single	Transverse/differential	No	10.1.3		10.3.3	n.a.
		Port to earth	No	10.1.3		10.3.3	10.4.2 Under study
		Port to external port	No	10.1.3		10.3.3	10.4.2 Under study

Table 2a – Applicable tests for external ports

Test type	Number of ports simultaneously tested	Test mode	Primary protection	Port type			
				Symmetric port	Coaxial port	Dedicated power feed port	Mains power port
Power induction and earth potential rise	Single	Transverse	Yes	10.1.3	Under study	10.3.3	n.a.
		Port to earth	Yes	10.1.3		10.3.3	Under study
		Port to external port	Yes	10.1.3		10.3.3	Under study
Neutral potential rise	Single	Port to earth	No	n.a.		n.a.	10.4.3
		Port to external port	No	n.a.		n.a.	10.4.3
Mains power contact	Single	Transverse Longitudinal	No	10.1.4		10.3.4	n.a.
		Port to earth	No	10.1.4		10.3.4	n.a.
		Port to external port	No	10.1.4		10.3.4	n.a.

Table 2b – Applicable tests for internal ports

Test type	Primary protection	Port type			
		Unshielded cable	Shielded cable	Floating d.c. power interface	Earthed d.c. power interface
Lightning voltage	No	10.5.1	10.5.2	10.5.3	10.5.4

10.1 External symmetric pair port

10.1.1 Lightning voltage

For equipment with high current carrying protection components, which eliminates the need for primary protection, the following applies:

- If this component is removable, an exception to clause 6 applies and it shall be removed and replaced by the special test protector for both the inherent and coordination tests, see clause 8.4.
- If this component is not removable, all tests are performed with the protection provided and the manufacturer must provide a test report to show that the inherent and coordination tests were performed with the special test protector during the design tests.

10.1.1.1 Single port

The single port lightning test checks that each port of the equipment has the required level of overvoltage resistibility. Transverse, port to earth, and port to external port tests shall be performed.

10.1.1.2 Multiple ports

The multiple ports lightning surge test checks that the equipment has the required level of resistibility when an overvoltage surge occurs on n ports simultaneously, which can result in a high current flowing into a common component or part of the equipment.

The number or percentage of ports to be tested simultaneously is specified in the product family or product Recommendation.

Both port to earth and port to external port tests shall be performed.

Care should be taken in the case where the equipment does not have SPDs to earth. The voltage at the equipment input should not be allowed to exceed the single port test $U_{c(max)}$.

10.1.2 Lightning current

The overcurrent test checks that the equipment has the required level of inherent resistibility when high current carrying protection components are installed within the equipment to eliminate the need for primary protection. This test checks the coordination of high current protectors, integral to the equipment, with connectors and printed circuits tracks, etc. The overcurrent test is specified in the product family or product Recommendation.

When applying the test to multiple wires, care should be taken to ensure that the current is divided equally between the wires. Particular care should be taken to ensure that the operation of one or more protectors does not prevent the operation of the other protectors.

Both port to earth and port to external port tests shall be performed.

10.1.3 Power induction and earth potential rise

Transverse, port to earth, and port to external port tests shall be performed.

If the equipment has high current carrying protection components, which eliminates the need for primary protection, the following applies:

- If this component is removable, an exception to clause 6 applies and it shall be removed and replaced by the special test protector for both the inherent and coordination tests, see clause 8.4.
- If this component is not removable, all tests are performed with the protection provided and the manufacturer must provide a test report to show that the inherent and coordination tests were performed with the special test protector during the design tests.

10.1.4 Mains power contact tests

Transverse, port to earth, and port to external port tests shall be performed. If the equipment has high current carrying protection components which eliminates the need for primary protection, the following applies:

- Perform the test with the protection as supplied by the manufacturer. Ensure that the protection operates during the test. This may require selecting a line with a protector which has a low firing voltage. It is not necessary to confirm protector operation if one or more of the following apply:
 - The equipment manufacturer, during the equipment design, has chosen the protector firing voltage so that the protector will not operate for power contact.
 - The equipment input impedance prevents the power contact voltage, at the input of the equipment, from exceeding the specified minimum firing voltage of the protector type.
- If this component is removable, an exception to clause 6 (equipment boundaries) applies and it shall be removed and replaced by the special test protector (see clause 8.4) and the tests repeated.

If this component is not removable, the manufacturer must provide a test report to show that the tests were repeated with a protector with a firing voltage equal to the specified minimum d.c. firing voltage during the design tests.

10.2 External coaxial port

ITU-T is studying the test requirements for coaxial cable ports.

10.3 External d.c. and a.c. dedicated power feeding ports

10.3.1 Lightning voltage

The lightning test is used to check that each port of the equipment has the required level of overvoltage resistibility. Transverse, port to earth, and port to external port tests shall be performed.

For equipment with high current carrying protection components, which eliminates the need for primary protection, the following applies:

- If this component is removable, an exception to clause 6 applies and it shall be removed and replaced by the special test protector for both the inherent and coordination tests, see clause 8.4.
- If this component is not removable, all tests are performed with the protection provided and the manufacturer must provide a test report to show that the inherent and coordination tests were performed with the special test protector during the design tests.

10.3.2 Lightning current

The overcurrent test checks that the equipment has the required level of inherent resistibility when high current carrying protection components are installed within the equipment to eliminate the need for primary protection. This test checks the coordination of high current protectors integral to the equipment, with connectors and printed circuits tracks, etc. The overcurrent test is specified in the product family or product Recommendation. Both port to earth and port to external ports tests shall be performed.

10.3.3 Power induction and earth potential rise

Transverse, port to earth, and port to external port tests shall be performed.

If the equipment has high current carrying protection components, which eliminates the need for primary protection, the following applies:

- If this component is removable, an exception to clause 6 applies and it shall be removed and replaced by the special test protector for both the inherent and coordination tests, see clause 8.4.
- If this component is not removable, all tests are performed with the protection provided and the manufacturer must provide a test report to show that the inherent and coordination tests were performed with the special test protector during the design tests.

10.3.4 Mains power contact

Transverse, port to earth, and port to external port tests shall be performed. If the equipment has high current carrying protection components which eliminates the need for primary protection, the following applies:

- Perform the test with the protection as supplied by the manufacturer. Ensure that the protection operates during the test. This may require selecting a line with a protector which has a low firing voltage. It is not necessary to confirm protector operation if one or more of the following apply:
 - The equipment manufacturer, during the equipment design, has chosen the protector firing voltage so that the protector will not operate for power contact.
 - The equipment input impedance prevents the power contact voltage, at the input of the equipment, from exceeding the specified minimum firing voltage of the protector type.
- If this component is removable, an exception to clause 6 (equipment boundaries) applies and it shall be removed and replaced by the special test protector (see clause 8.4) and the tests repeated.

If this component is not removable, the manufacturer must provide a test report to show that the tests were repeated with a protector with a firing voltage equal to the specified minimum d.c. firing voltage during the design tests.

10.4 External a.c. mains power port

10.4.1 Lightning voltage

Transverse, port to earth, and port to external port tests shall be performed.

Three types of primary protector SPDs are known to exist for use on the electricity supply mains, and these are:

- 1) clamping (MOV) type;
- 2) switching (spark gap);
- 3) a combination of both.

Because of the different characteristics of these SPDs, a manufacturer may need to check that this equipment coordinates with all three types.

10.4.2 Earth potential rise

ITU-T is studying the need for a test to check resistibility of the equipment from the earth potential rise which can occur when a high voltage (HV) earth fault occurs on the substation providing mains power to the equipment.

10.4.3 Neutral potential rise

This test applies only on the request of the network operator, and when the neutral is not connected to the protective earth (i.e., a TT or IT mains system). An example of such a configuration is described in clause II.5.

10.5 Internal ports

10.5.1 Unshielded cable

The lightning voltage test is to check that the equipment port has the required level of overvoltage resistibility. Only a longitudinal test is performed.

10.5.2 Shielded cable

The lightning voltage test is to check that the equipment port has the required level of overvoltage resistibility. Only a longitudinal test is performed.

10.5.3 Floating d.c. power interface

The lightning voltage test is to check that the equipment port has the required level of overvoltage resistibility. Only a longitudinal test is performed.

10.5.4 Earthed d.c. power interface

The lightning voltage test is to check that the equipment port has the required level of overvoltage resistibility. Only a longitudinal test is performed.

Annex A

Test schematics

(This annex forms an integral part of this Recommendation)

A.1 Introduction

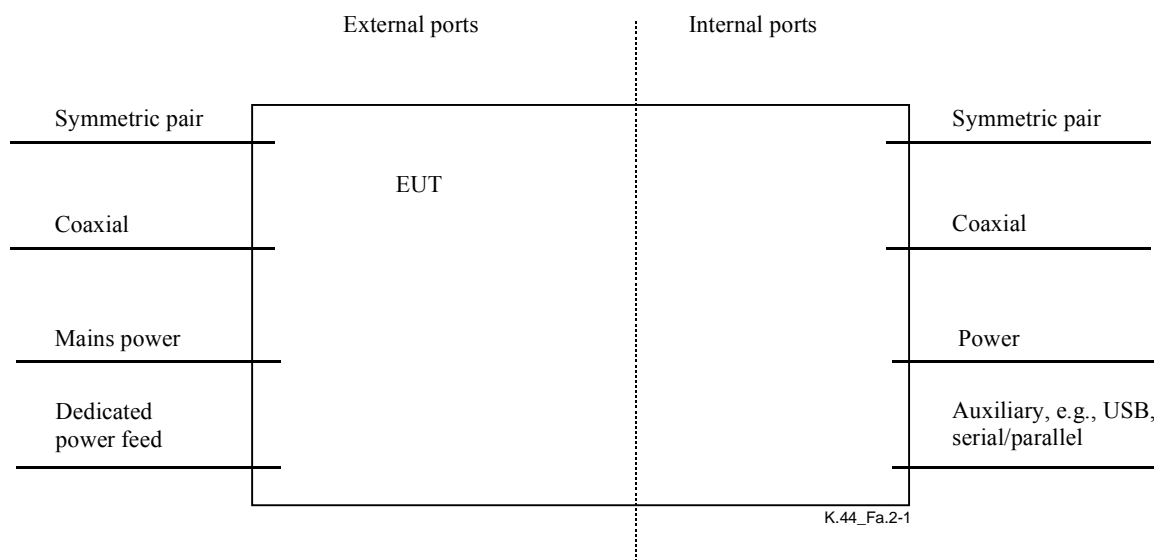
Equipment needs to be tested in all likely states and conditions. This means that the test specified in each line of the test table may need to be performed many times.

To ensure repeatability of testing by test houses and manufacturers, it is necessary to ensure that the tests are performed in the same way. Below are the generator circuits, coupling, decoupling and powering circuits, the termination of untested ports, and the connection to the equipment under test (EUT).

A.2 Equipment

A.2.1 Equipment ports

Figure A.2-1 shows the possible ports of a piece of equipment.



NOTE 1 – Not all ports need to be tested but they may need to be terminated.

NOTE 2 – In this figure, "External ports" means ports connected to cables which exit the building and "Internal ports" means ports connected to cables which remain within the building.

Figure A.2-1 – Equipment port types

Figure A.2-2 shows the classification of ports of equipment.

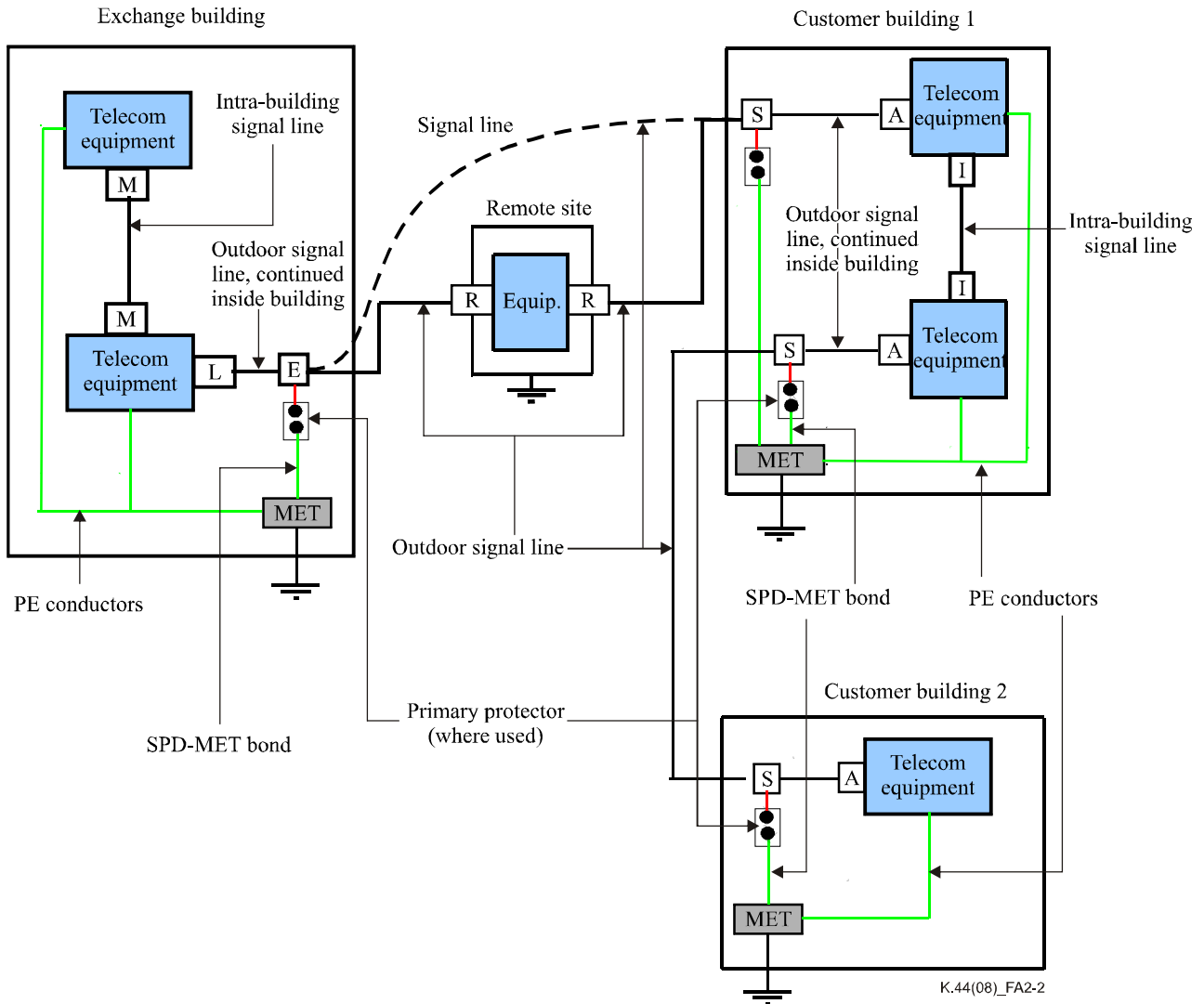


Figure A.2-2 – Classification of external and internal ports

Table A.2-1 – Description of Nodes

Node	Description
L	Transition between equipment interface inside the exchange building and the external cabling.
E	Entrance of the exchange building, e.g., MDF.
R	Transition between line and equipment inside a remote site.
S	External cable termination point.
A	Transition between equipment interface inside the customer's building and the external cabling.
M	Transition between equipment interface inside the exchange's building and the internal cabling.
I	Transition between equipment interface inside the customer's building and the internal cabling.

It is necessary to consider the differences between external ports, internal ports and intra-system ports.

An equipment port can only be classified as an intra-system port if both of the following apply:

- the port is cabled to an intra equipment port of the same system; and
- the cabling is installed according to the equipment manufacturer's directions.

An equipment port can only be classified as an internal port if all of the following apply:

- it is only connected to intra-building cables;
- the cable is connected to an internal port of the associated equipment;
- the equipment and the associated equipment have the same earth reference or the equipment is floating;
- the port will not be connected to an external port of the associated equipment;
- the port does not provide a service which the customer may extend to an outbuilding (e.g., a POTS, Ethernet or video port);
- the port will not have a conductive connection to a cable which leaves the building via other equipment (e.g., via a splitter).

Any port not complying with the requirements for an intra-system port or an internal port is an external port.

Figure A.2-3 is an example of port classifications.

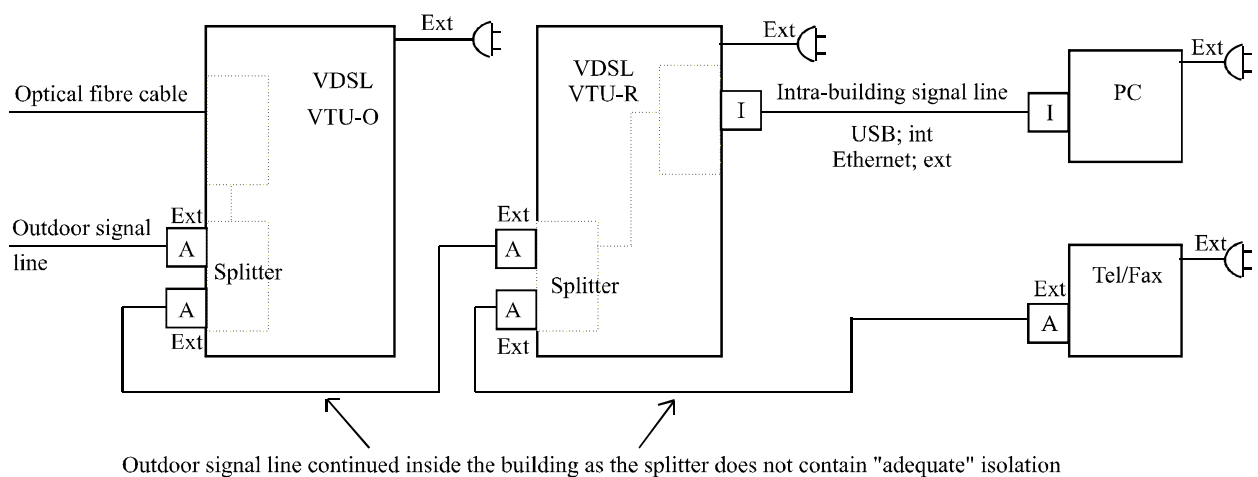


Figure A.2-3 – Example of port classifications

Antenna ports on equipment need to be classified according to the location of the antenna and the intended use of the equipment. Where the equipment will only be connected to antennas installed in an inherently protected location, i.e., the shaded area in Figure A.2-4, the antenna port could be classified as an internal port. If the port could be connected to antennas installed in exposed locations, e.g., antenna positions 1 and 2, the antenna port should be classified as an external port. If it is unclear where the antenna may be installed, it is best to be conservative and classify the antenna port as an external port.

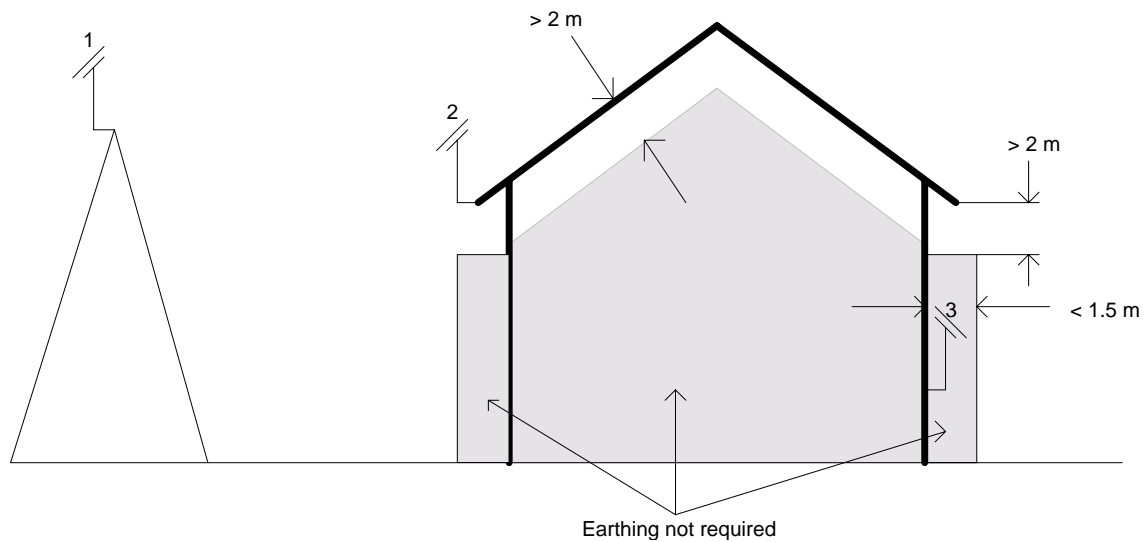


Figure A.2-4 – Classification of antenna ports

A.2.2 Equipment type

Equipment may be of two general types: earthed and floating. Generally, telecommunication centre equipment will be of the earthed type. Access network equipment and customer equipment may be either type.

A.2.3 Protection type

Protecting equipment from high current surges is achieved by either installing primary protection or using equipment with integral high current protection. Generally, telecommunication centre equipment will be protected by primary protection installed on the MDF. Access network equipment may be protected using either method. Customer equipment would normally be protected by installing primary protection.

A.2.4 Equipment conditions and states

As the components in the equipment, which are connected to the equipment port under test, may vary depending on which state the equipment is in, the equipment must be tested in all operating states of significant duration. Examples of equipment states that may need to be considered include:

- handset "on hook" and "off hook";
- power feed "on" and "off";
- during ring;
- during line test cycle, etc.

A.3 Test generators

Examples of circuits of test generators, which can be used to generate the waveshapes specified in clause A.4, are contained in Figures A.3-1 to A.3-6. While the components shown should give the correct waveshape, they may require adjustment.

Alternative test generators may be used providing that they give the same result.

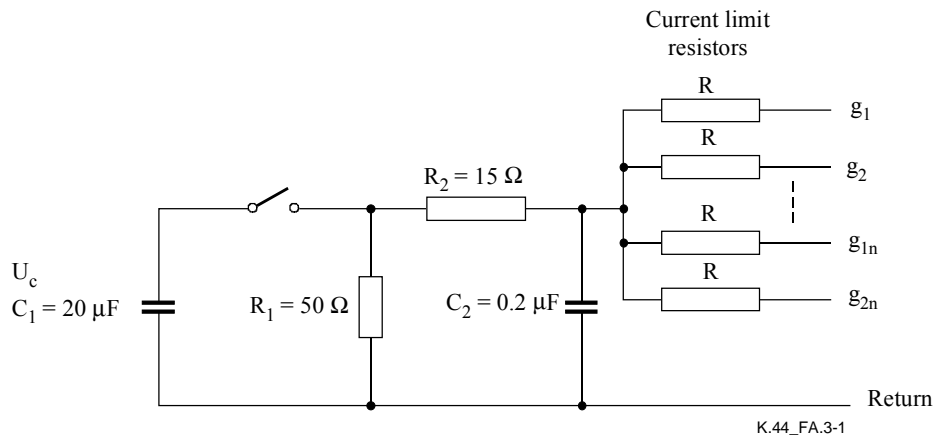


Figure A.3-1 – 10/700 μ s voltage surge generator

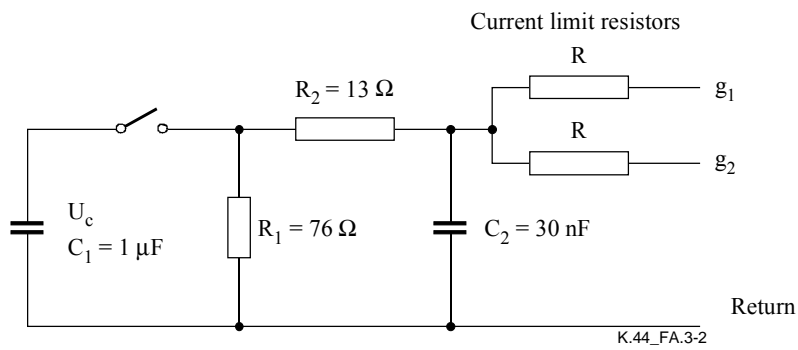
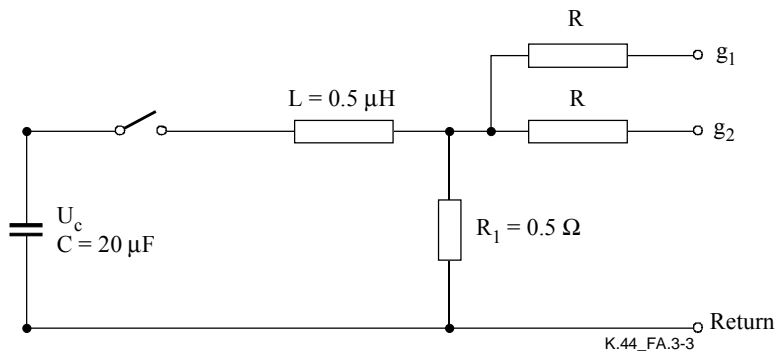


Figure A.3-2 – 1.2/50 μ s voltage surge generator

The test generator may be a combination wave generator according to [IEC 61000-4-5] (Figure A.3-5) or an equivalent 1.2/50 μ s voltage surge generator.



L is small and mostly parasitic inductance of the wiring, may need to be adjusted to give the required front time of 2 μ s. U_c is adjusted to give required o/c output voltage.

Figure A.3-3 – 2/10 μ s voltage surge generator

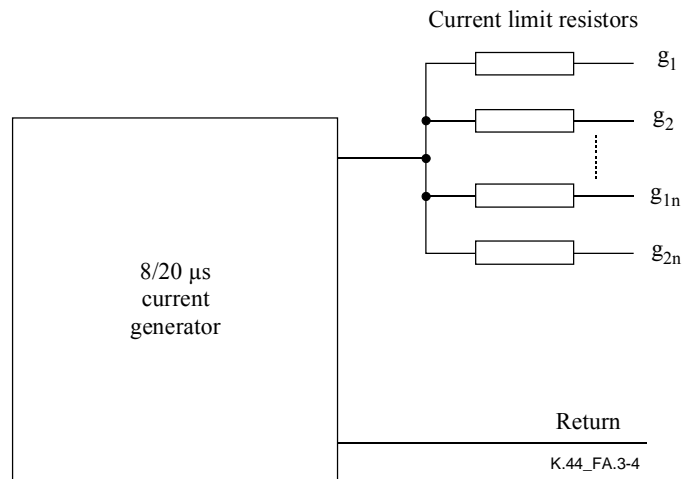


Figure A.3-4 – 8/20 μs current generator

The test generator may be:

- a combination wave generator according to [IEC 61000-4-5] (Figure A.3-5);
- any 8/20 surge current generator of 8/20 μs waveshape.

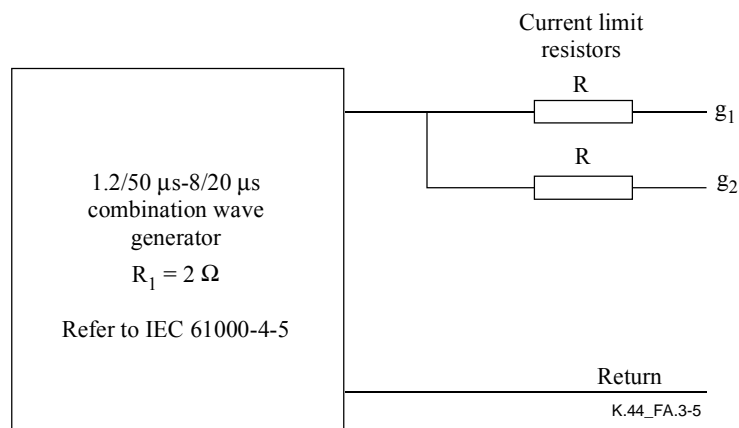
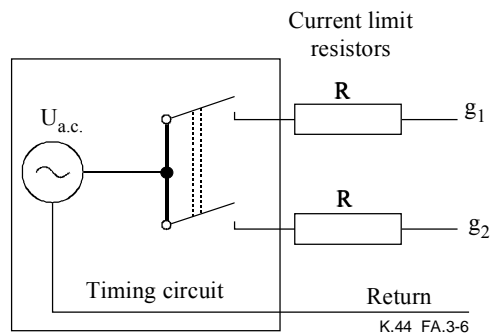


Figure A.3-5 – Combination wave generator



For the value of R, refer to the appropriate test table in the appropriate product Recommendation.

NOTE – If national regulations require it, the maximum current may be limited.

Figure A.3-6 – Power induction, power contact and rise of neutral potential generator

A.4 Waveform generation

Where circuit values are provided, use this circuit. Where generator circuits are not given, refer to the quoted IEC standard or [IEC 60060-1] for guidance on verifying the waveshape.

The following tolerances should be observed for both the power induction and power contact tests:

Voltage	−0% to +5%
Current	−0% to +5%
Time	−0% to +10%

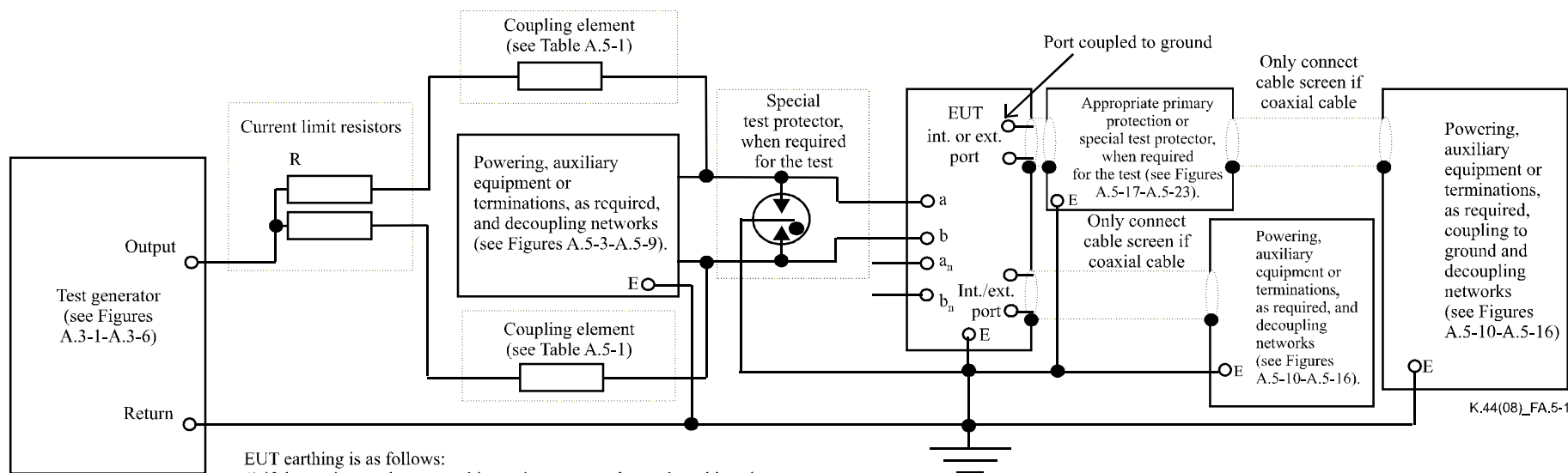
The procedure for verifying the tolerances of the above parameters for Figure A.3-6 is given below

- Step 1 With both of the output terminals g_1 and g_2 in an open-circuit condition, check that the voltage is within the allowed tolerance.
- Step 2 With both of the output terminals g_1 and g_2 in short-circuit condition, check that the current is within the allowed tolerance.
- Step 3 With the output terminal g_1 in an open-circuit condition and with g_2 in a short-circuit condition, check that the voltage on terminal g_1 and the current in circuit g_2 are within the allowed tolerance.
- Step 4 With the output terminal g_2 in an open-circuit condition and with g_1 in a short-circuit condition, check that the voltage on terminal g_2 and the current in circuit g_1 are within the allowed tolerance.
- Step 5 With both of the output terminals g_1 and g_2 in an open-circuit condition, check that the length of the surge is within the allowed tolerance.

A.5 Powering, coupling, decoupling and terminations

A.5.1 General

The surge generator, powering, coupling and decoupling elements, the EUT and terminations are connected as shown in Figure A.5-1.



EUT earthing is as follows:

- 1) if the equipment has an earthing point, connect the earth to this point;
- 2) if the equipment has a conductive case, but does not have an earthing point, connect the earth to the case;
- 3) if the equipment has neither an earth point nor a conductive case, let the equipment float.

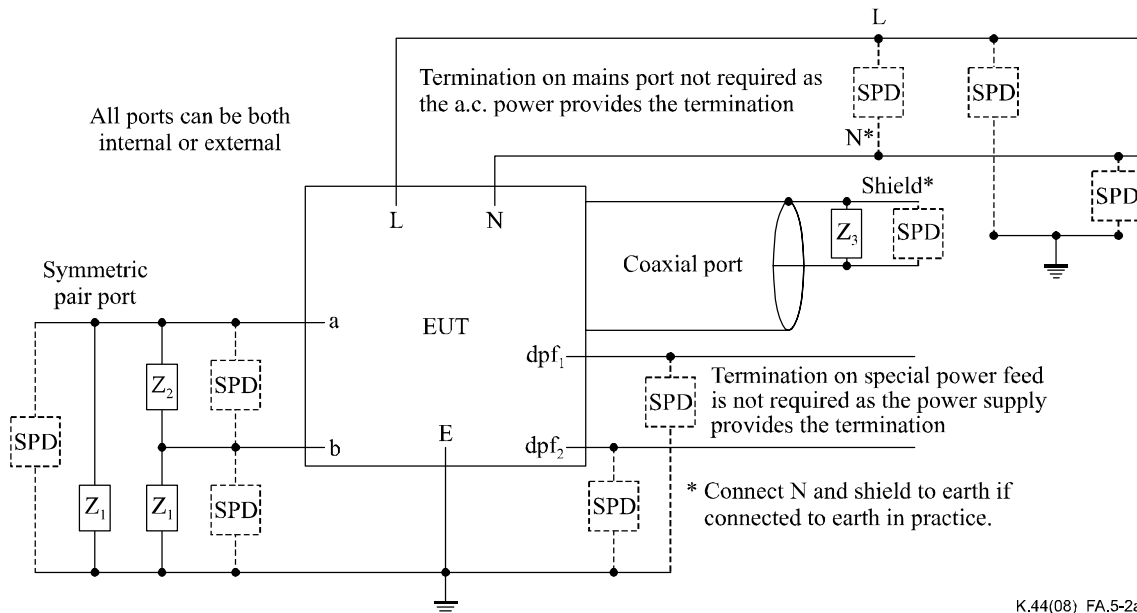
Figure A.5-1 – Block diagram of a typical test set-up

Coupling elements are used to connect the surge generator to the EUT and to connect other ports/lines to ground during port-to-port testing. The coupling element, if required, can be an MOV, a GDT, a capacitor or any other element with an operating voltage in excess of the maximum EUT working voltage. The coupling element should be considered as an integral part of the test generator and should not significantly affect the open-circuit voltage nor the short-circuit current. It may be necessary to increase the test voltage to compensate for voltage drop in coupling elements. There are a number of ways of connecting coupling elements to ground and some examples are shown in Figure A.5-2b.

Decoupling elements are used to reduce the surge energy, which would otherwise enter the powering equipment, auxiliary equipment or terminations. The decoupling elements, if necessary, can be an impedance that blocks the surge energy from entering the line simulator (e.g., a resistance of 200 Ω or greater, for symmetric pair circuits, an inductor or a choke) but still allowing power and signalling to take place to the EUT. It has to be proven (e.g., by calibration) that the decoupling network does not influence the pulse shape and the test level; otherwise, the test levels have to be adjusted to achieve the correct level. The equipment is powered via the mains or dedicated power feed (dpf) port, etc., through an appropriate decoupling network, e.g., isolation transformer or chokes, etc.

An example of terminations of untested ports is given in Figure A.5-2a. All ports, including the test port, would normally be terminated in some way. Decoupling elements are used to prevent damage to the auxiliary equipment or termination. When required for the test, the appropriate untested port is coupled to ground by using a coupling element.

NOTE – For high speed data circuits it has been found that a more accurate result can be achieved by connecting up to 100 metres of cable between the EUT and the associated data circuit equipment. Using a simple termination may not detect data problems which can later be experienced in the field.



Z₁, Z₂ and Z₃ are the nominal terminations for a working system or associated equipment. The SPDs are used to couple the required untested port to ground in turn.

K.44(08)_FA.5-2a

Figure A.5-2a – Example of termination and coupling to ground of untested port

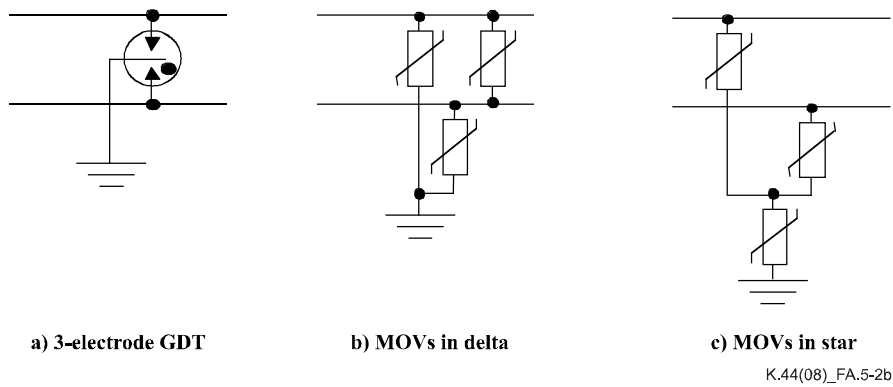


Figure A.5-2b – Examples of connecting coupling elements to ground

Recommended component values for coupling and decoupling elements are provided in Table A.5-1. Record the method used in the test report.

Table A.5-1 – Recommended coupling and decoupling elements

Port type	Test ports		Untested ports		
	Generator coupling elements	Decoupling element	Decoupling element	Coupling element to ground	Protection for untested port on EUT
External symmetric pair ports	GDTs or MOVs	See Figure A.5-3	See Figure A.5-10	GDT, see Figure A.5-10	GDT, see Figure A.5-17
External coaxial cable	Under study	See Figure A.5-4	See Figure A.5-11	A link, see Figure A.5-11	GDT, see Figure A.5-18
External dpf cable ports	MOVs	See Figure A.5-5	See Figure A.5-12	MOVs, see Figure A.5-12	MOVs, see Figure A.5-19
Mains power ports	MOVs	See Figure A.5-6	See Figure A.5-13	MOV, see Figure A.5-13	MOV, see Figure A.5-20
Internal unshielded cable ports	GDTs or MOVs	See Figure A.5-7	See Figure A.5-14	Clamping diodes, see Figure A.5-14	Clamping diodes, see Figure A.5-21
Internal shielded cable ports	None required, see Figure A.6.5-2	See Figure A.5-8	See Figure A.5-15	A link, see Figure A.5-15	GDT, see Figure A.5-22
Internal d.c. power ports	MOVs	See Figure A.5-9	See Figure A.5-16	MOVs, see Figure A.5-16	MOVs, see Figure A.5-23

A.5.2 Tested ports

A.5.2.1 External symmetric pair

When an external symmetric port is the tested port, it is suggested that 200 Ω be inserted in series with each line leg between the AE and the generator. A 33 k Ω in parallel with a 125 V clamping device may be connected between each line leg and ground at the AE to further decouple the AE, see Figure A.5-3. This will limit the current conducted into the AE to a few amps but still allow xDSL, POTS or ISDN transmission even when remote power feeding up to 120 VDC is used. Other values or methods, e.g., an artificial cable, are allowed.

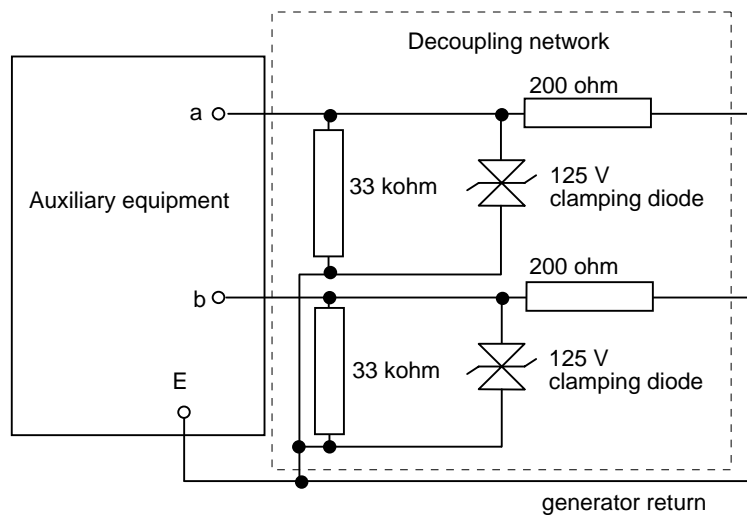


Figure A.5-3 – Decoupling network for AE connected to the tested external symmetric pair port

A.5.2.2 External coaxial cable port

Under study.

Figure A.5-4 – Decoupling network for AE connected to the tested external coaxial cable ports

A.5.2.3 External dedicated power feed port

When an external dedicated power feed port is the tested port, it is suggested that 3 mH be inserted in series with each line leg between the AE and the generator. A 125 V clamping device may be connected between each line leg and ground at the AE to further decouple the AE, see Figure A.5-5. This will limit the current conducted into the AE to a few amps for power feeding up to 120 VDC. Other values or methods, e.g., an artificial cable, are allowed.

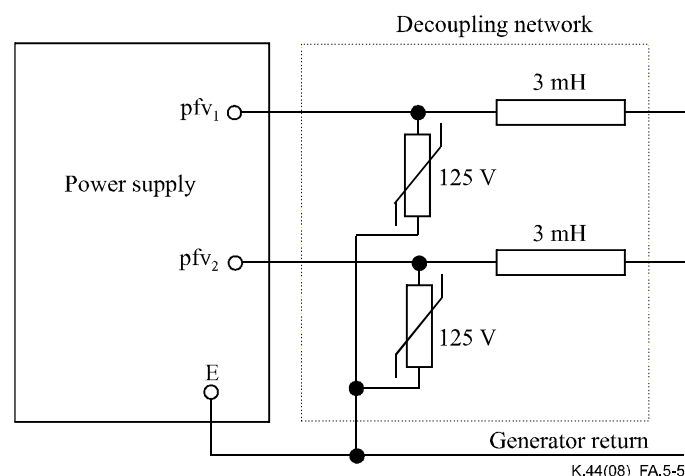


Figure A.5-5 – Decoupling network for AE connected to the tested external dpf pair port

A.5.2.4 Mains ports

When the mains port is the tested port, it is necessary to decouple the mains source during testing for transverse, port to earth and port to external port surges to protect the power source. Proposed decoupling elements are shown in Figure A.5-6 below.

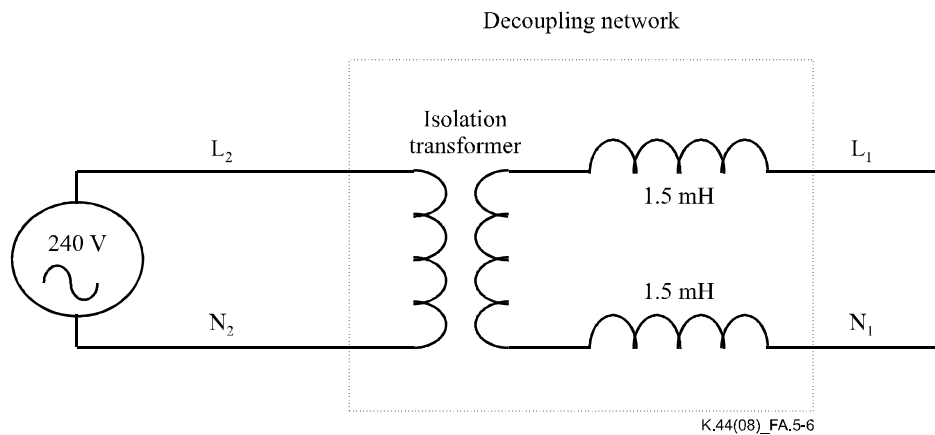


Figure A.5-6 – Decoupling network for the power supply connected to the tested mains port

If the recommended decoupling element cannot be used for the test, this fact should be noted in the test report. The value of the modified decoupling element should be reported along with the potential impact on the test result.

A.5.2.5 Internal unshielded cable port

When an internal unshielded cable port is the tested port, it is suggested that $200\ \Omega$ be inserted in series with each line leg between the AE and the generator. A $33\ \text{k}\Omega$ in parallel with an 18 V clamping device may be connected between each line leg and ground at the AE to further decouple the AE. This will limit the current conducted into the AE to a few amps. Other values or methods are allowed.

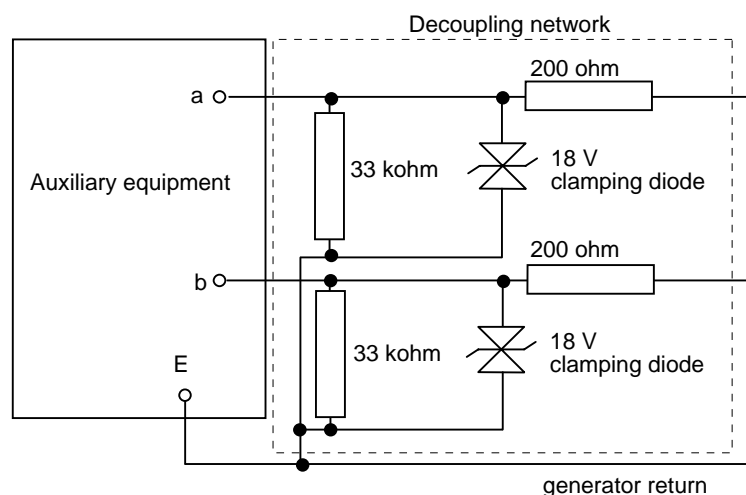
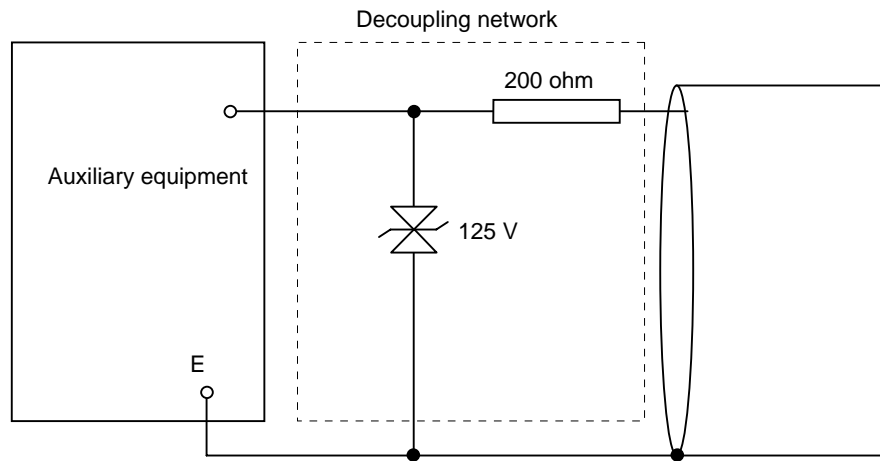


Figure A.5-7 – Decoupling network for AE connected to internal unshielded cable ports

A.5.2.6 Internal shielded cable port

When an internal coaxial cable port is the tested port, it is suggested that 200 Ω be inserted in series with the centre conductor between the AE and the generator. A 125 V clamping device may be connected between the centre conductor and ground at the AE to further decouple the AE, see Figure A.5-8. This will limit the current conducted into the AE to a few amps for power feeding up to 120 VDC. Where this prevents correct functioning of the system, other values or methods, e.g., an artificial cable or 100 metres of cable, are allowed. The method used should be recorded in the test report.



Note, where a 200 ohm resistor cannot be used, 100 m of coaxial cable may provide sufficient decoupling

Figure A.5-8 – Decoupling network for the auxiliary equipment connected to the tested internal coaxial cable port

A.5.2.7 Internal d.c. power interface

When an internal d.c. power port is the tested port, it is suggested that 3 mH be inserted in series with each line leg between the AE and the generator. A 115 V clamping device may be connected between each line leg and ground at the AE to further decouple the AE, see Figure A.5-9. This will limit the current conducted into the AE to a few amps for power feeding up to 100 VDC. Other values or methods, e.g., an artificial cable, are allowed.

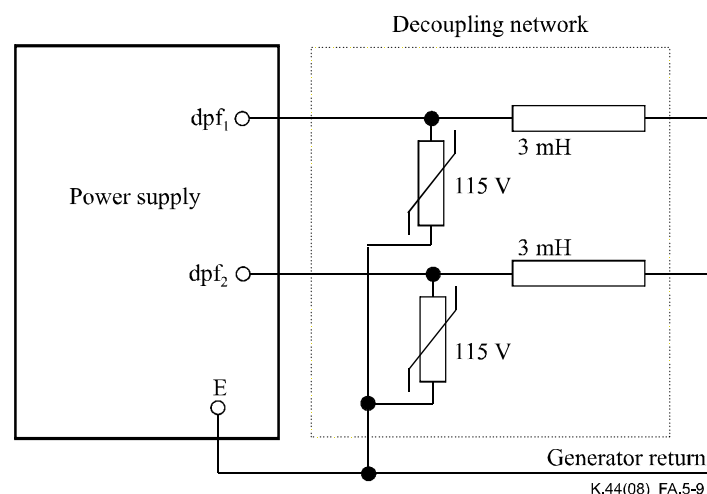


Figure A.5-9 – Decoupling network for the power supply connected to the tested internal d.c. power port

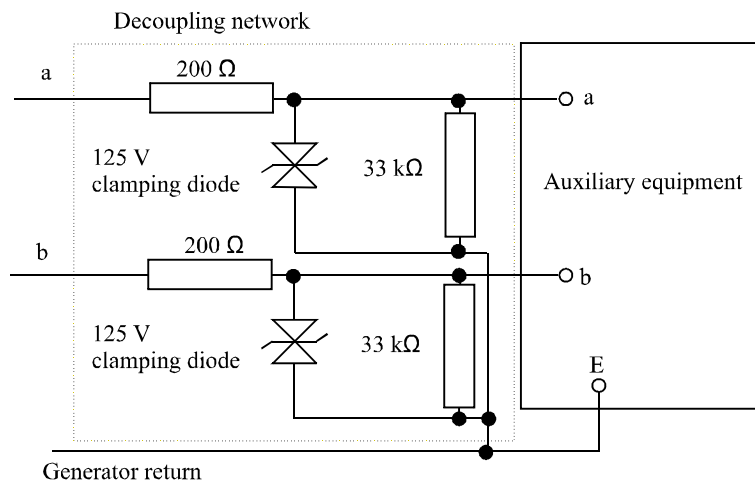
The generator coupling elements consist of a 10 Ω resistor and a 9 μF capacitor connected in series.

A.5.3 Untested ports

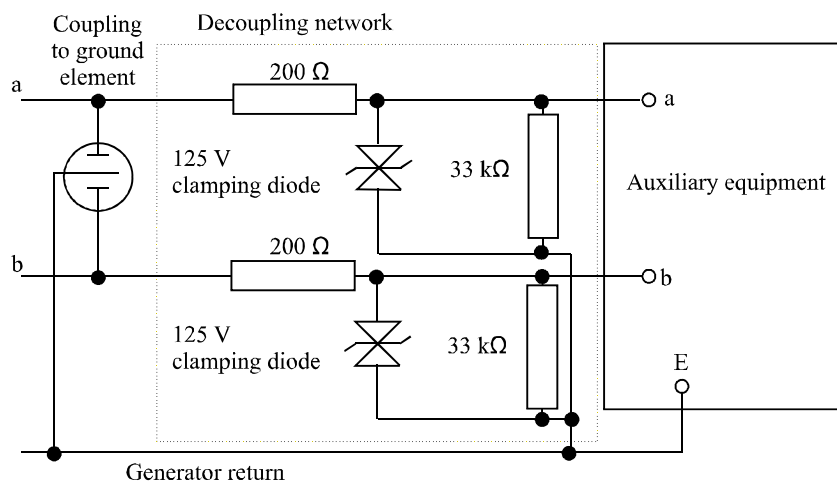
A.5.3.1 External symmetric pair

When an external symmetric port is the untested port, it is suggested that 200 Ω be inserted in series with each line leg between the AE and the generator. A 33 kΩ in parallel with a 125 V clamping device may be connected between each line leg and ground at the AE to further decouple the AE. This will limit the current conducted into the AE to a few amps but still allow xDSL, POTS or ISDN transmission even when remote power feeding up to 120 VDC is used.

The methods of termination and coupling to earth for untested external symmetric pair ports are shown in Figure A.5-10.



a) Termination of an untested external symmetric pair port



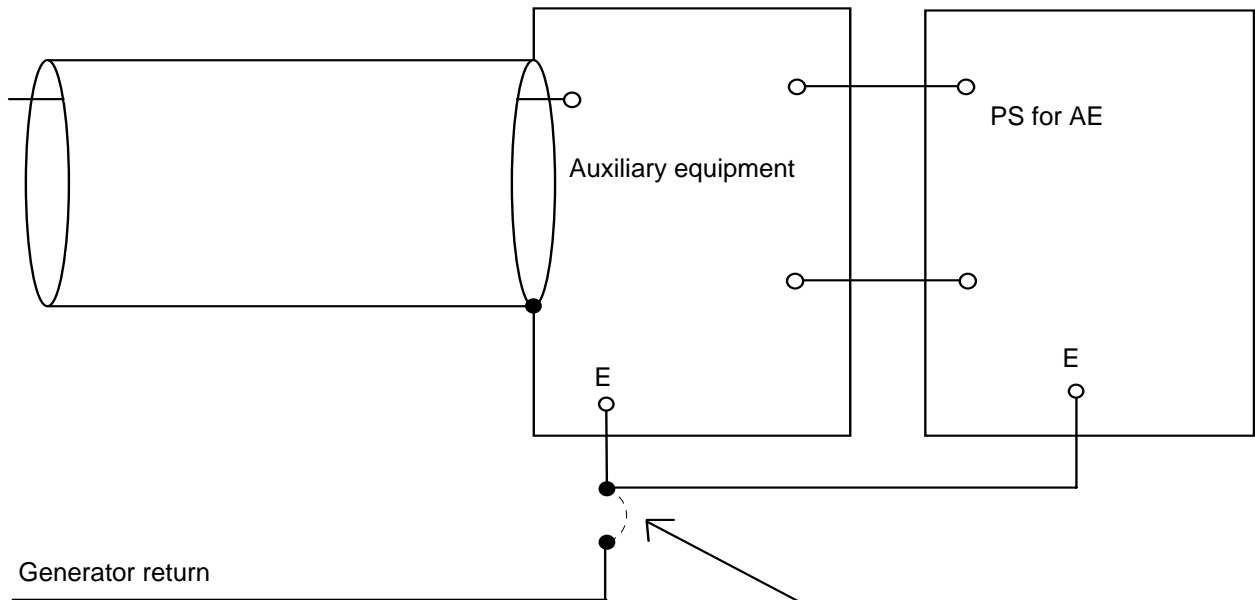
b) Termination and coupling to ground of an untested external symmetric pair port

K.44(08)_FA.5-10

Figure A.5-10 – Termination and coupling to ground of untested external symmetric pair ports

A.5.3.2 External coaxial cable port

When an external coaxial cable port is the untested port, it is suggested that the methods of termination and coupling to earth shown in Figure A.5-11 are used. Float the AE, and its power source, to "decouple" the AE. Ground the AE and its power supply to "couple" the EUT port to ground, see Figure A.5-18.

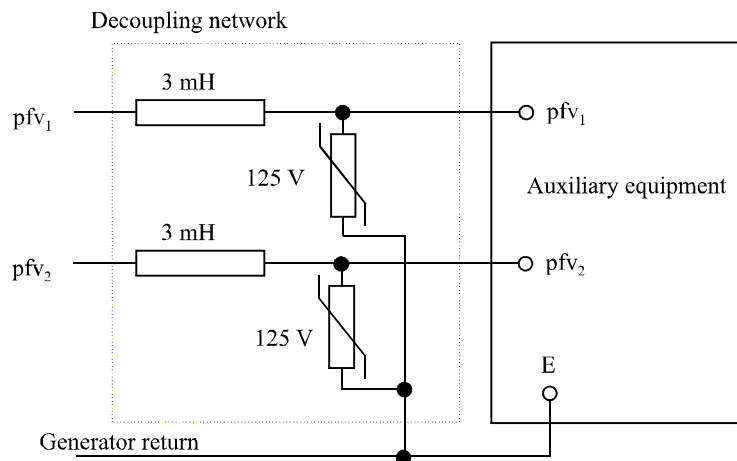


Remove link to decouple untested port from ground (terminated only)
Insert link to couple untested port to ground (normal operation)

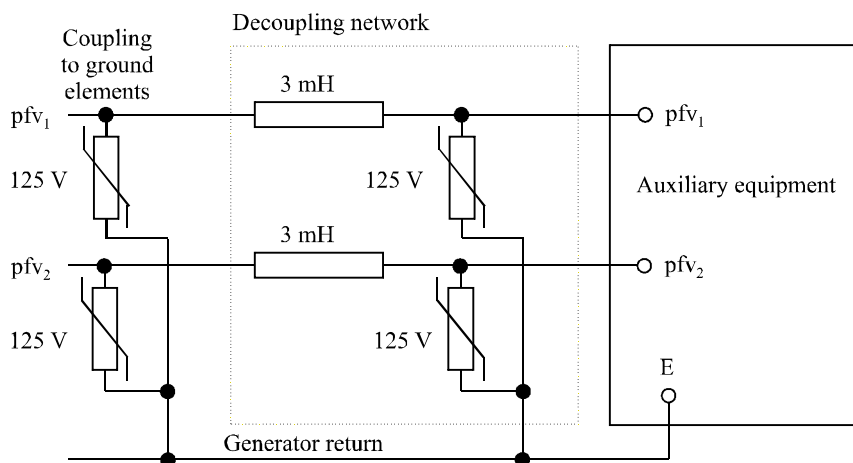
Figure A.5-11 – Termination and coupling to ground of untested external coaxial cable ports

A.5.3.3 External dedicated power feed port

When an external dedicated power feed port is the untested port, it is suggested that 3 mH be inserted in series with each line leg between the AE and the generator. A 125 V clamping device may be connected between each line leg and ground at the AE to further decouple the AE, see Figure A.5-12. This will limit the current conducted into the AE to a few amps for power feeding up to 120 VDC. Other values or methods, e.g., an artificial cable, are allowed.



a) Termination of an untested external dpf pair port



b) Termination and coupling to ground of an untested external dpf pair port

K.44(08)_FA.5-12

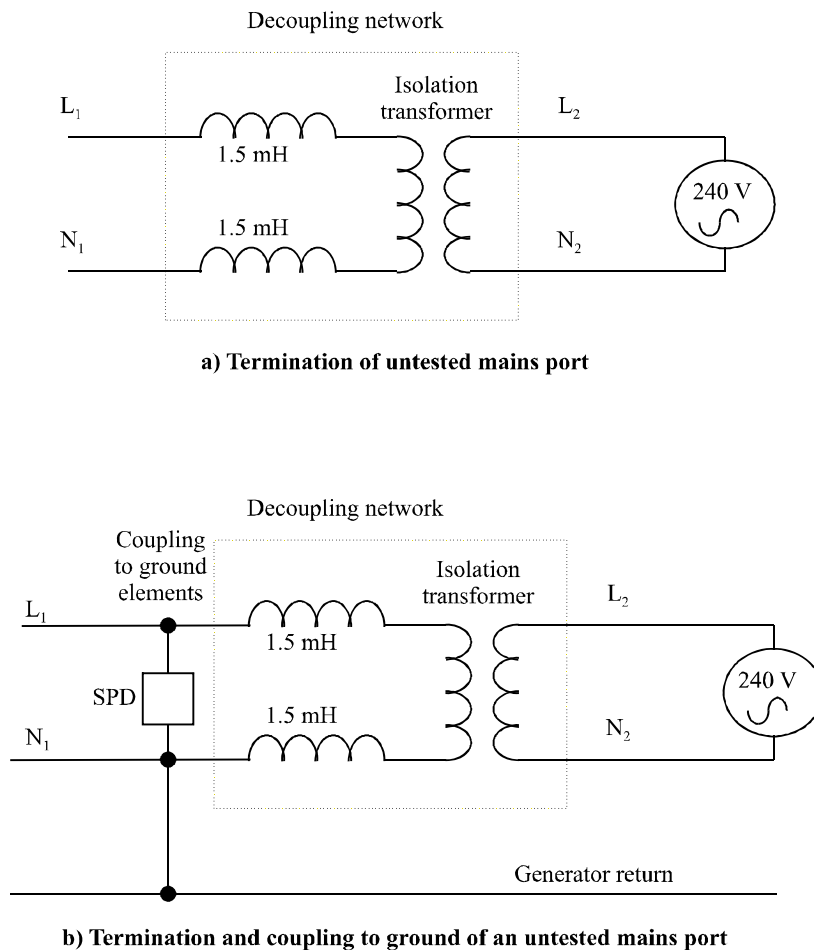
Figure A.5-12 – Termination and coupling to ground of untested dpf ports

A.5.3.4 Mains ports

When the mains port is an untested port, three states for the mains network have to be considered, and these are:

- The mains distribution network appears as a high impedance network. This applies for a non-earthed neutral installation, e.g., a TT power distribution system. In this case, use 1.5 mH inductors in the L1 and N conductors.
- The neutral is grounded at the customer premises, e.g., a TN-C power distribution system. In this case, connect the neutral conductor to the generator return.
- Both L1 and neutral are grounded under surge conditions, i.e., SPDs have been installed. In this case, connect the neutral to ground and install an SPD L1 to N/E.

To test all possible scenarios and to allow testing under the conditions where the port is floating and coupled to earth, use the termination and coupling to earth methods shown in Figure A.5-13.

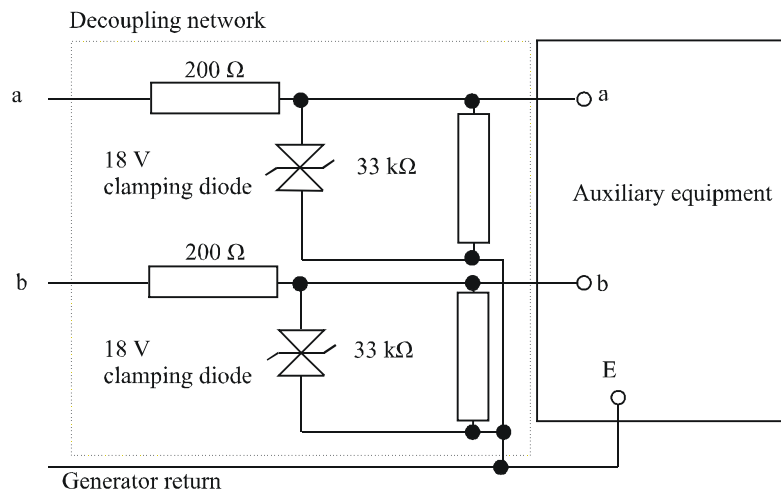


K.44(08)_FA.5-13

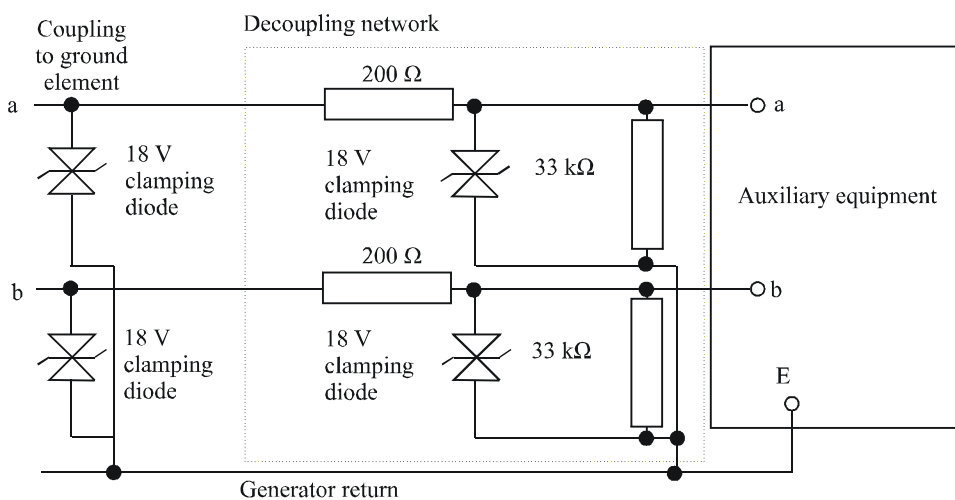
Figure A.5-13 – Terminating and coupling to ground of untested mains ports

A.5.3.5 Internal unshielded cable port

When an internal unshielded cable port is the untested port, it is suggested that 200 Ω be inserted in series with each line leg between the AE and the generator. A 33 kΩ in parallel with an 18 V clamping device may be connected between each line leg and ground at the AE to further decouple the AE, see Figure A.5-14. This will limit the current conducted into the AE to a few amps. Other values or methods, e.g., an artificial cable, are allowed.



a) Termination of untested internal unshielded pair cable ports



b) Termination and coupling to ground of untested internal unshielded pair cable ports

K.44(08)_FA.5-14

Figure A.5-14 – Terminating and coupling to ground of untested internal unshielded pair cable ports

A.5.3.6 Internal shielded cable port

When an internal shielded cable port is the untested port, it is suggested that the methods of termination and coupling to earth shown in Figure A.5-15 are used:

- To "decouple" the AE from ground: float the AE and its power supply.
- To "couple" the AE to ground: connect the AE and its power supply to the generator return.

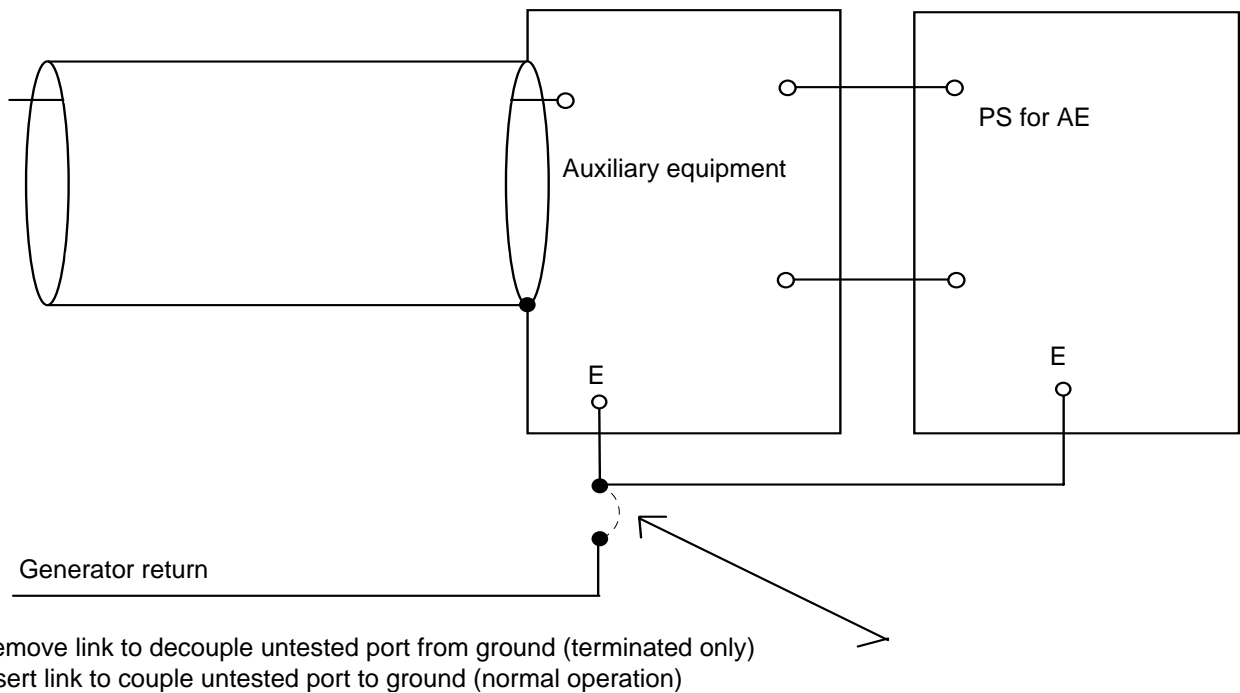
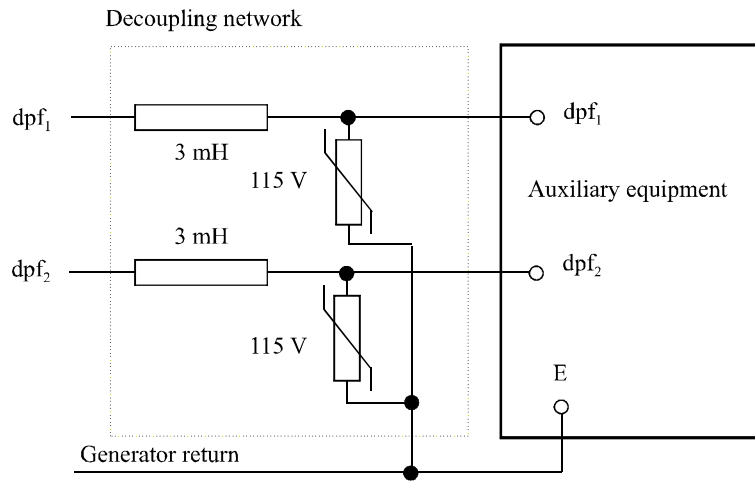


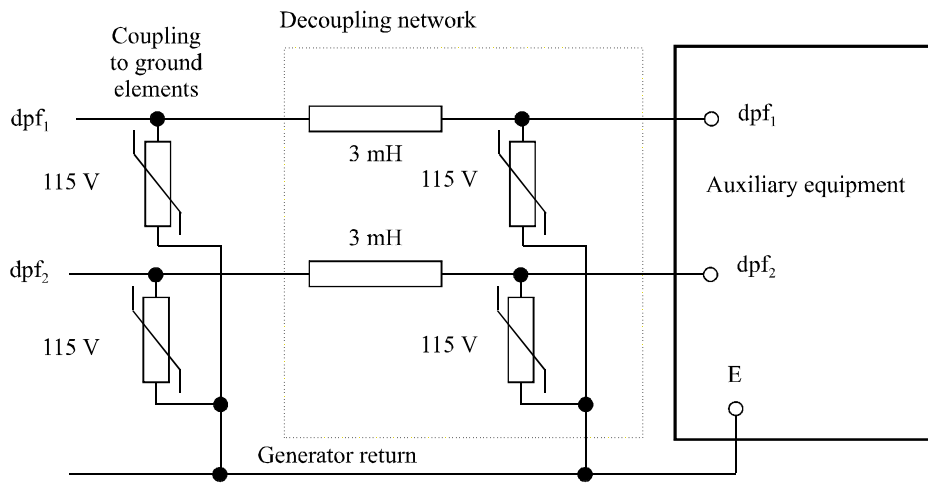
Figure A.5-15 – Terminating and coupling to ground of untested internal shielded cable ports

A.5.3.7 Internal d.c. power interface

When an internal d.c. power port is the untested port, it is suggested that 3 mH be inserted in series with each line leg between the AE and the generator. A 115 V clamping device may be connected between each line leg and ground at the AE to further decouple the AE, see Figure A.5-16. This will limit the current conducted into the AE to a few amps for power feeding up to 100 VDC. Other values or methods, e.g., an artificial cable, are allowed.



a) Termination of an untested internal d.c. power port



b) Termination and coupling to ground of an untested internal d.c. power port

K.44(08)_FA.5-16

Figure A.5-16 – Terminating and coupling to ground of untested internal d.c. power interfaces

A.5.4 Protection elements

When performing the coordination test for a tested port to an untested external or internal port, it is necessary to install protection for the EUT on the external or internal port which is coupled to ground.

A.5.4.1 External symmetric pair

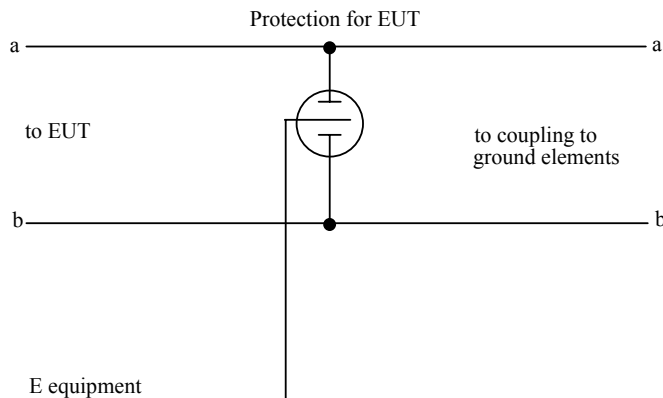


Figure A.5-17 – Connection of protection for the untested external symmetric pair port coupled to ground

A.5.4.2 External coaxial cable port

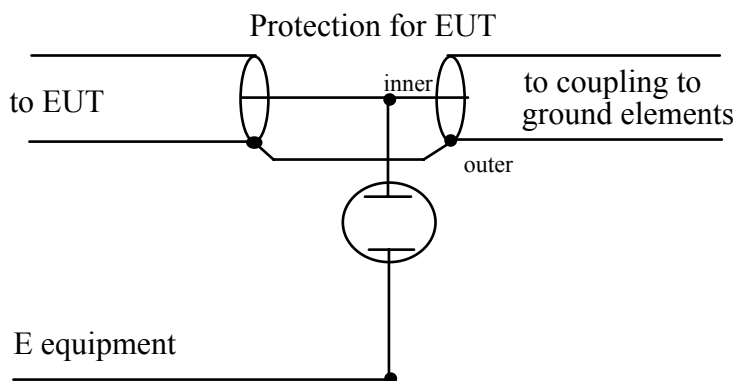
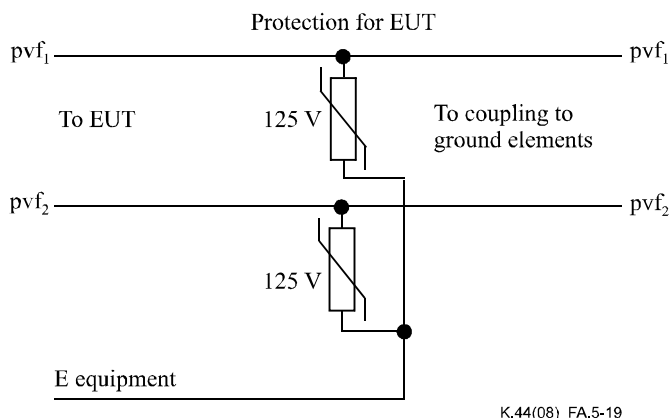


Figure A.5-18 – Connection of protection for the untested external coaxial cable port coupled to ground

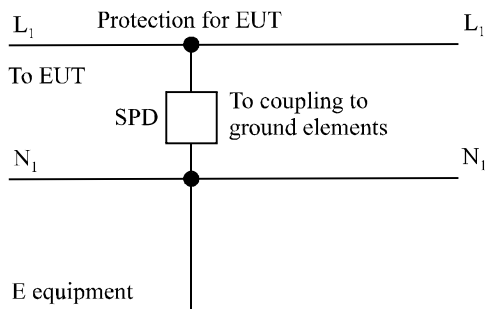
A.5.4.3 Dedicated power feed port



K.44(08)_FA.5-19

Figure A.5-19 – Connection of protection for the untested external dedicated power feed port coupled to ground

A.5.4.4 Mains power port



K.44(08)_FA.5-20

Figure A.5-20 – Connection of protection for the untested external mains power port coupled to ground

A.5.4.5 Internal symmetric pair

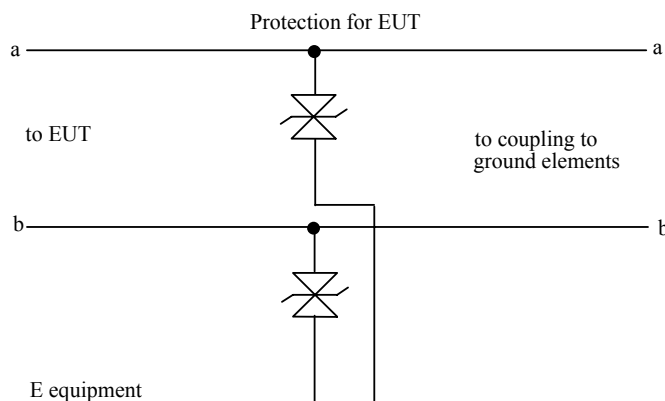


Figure A.5-21 – Connection of protection for the untested internal symmetric pair port coupled to ground

A.5.4.6 Internal shielded cable port

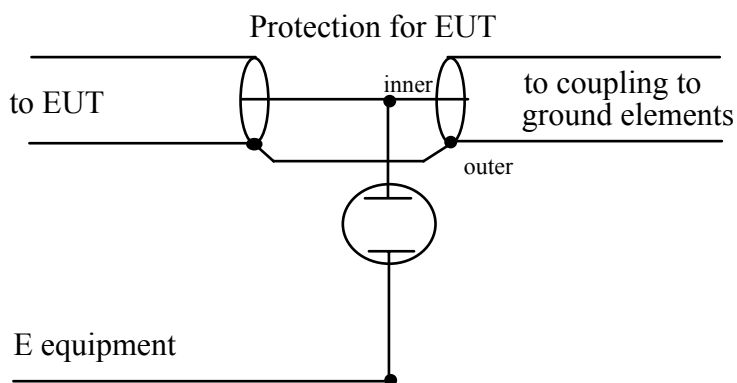


Figure A.5-22 – Connection of protection for the untested internal shielded cable port coupled to ground

A.5.4.7 Internal power feed port

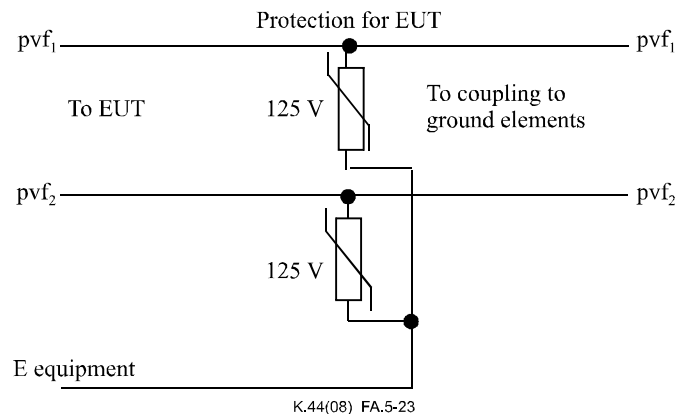


Figure A.5-23 – Connection of protection for the untested internal power feed port coupled to ground

A.6 Test schematics for different types of ports

A.6.1 Symmetric pair ports

Figures A.6.1-1a and A.6.1-1b give the schematic for applying transverse surges. Figure A.6.1-2 gives the schematic for applying surges port to earth. Figure A.6.1-3 gives the schematic for applying surges from an external port to an external port. Figure A.6.1-4 gives the schematic for applying surges to multiple external ports to earth. Figure A.6.1-5 gives the schematic for applying surges to multiple external ports to an external port.

A.6.2 Coaxial ports

See Figures A.6.2-2 and A.6.2-3.

A.6.3 a.c. or d.c. dedicated power feed ports

Figures A.6.3-1a and A.6.3-1b give the schematic for applying transverse surges. Figure A.6.3-2 gives the schematic for applying surges port to earth. Figure A.6.3-3 gives the schematic for applying surges from an external port to an external port.

A.6.4 Mains power ports

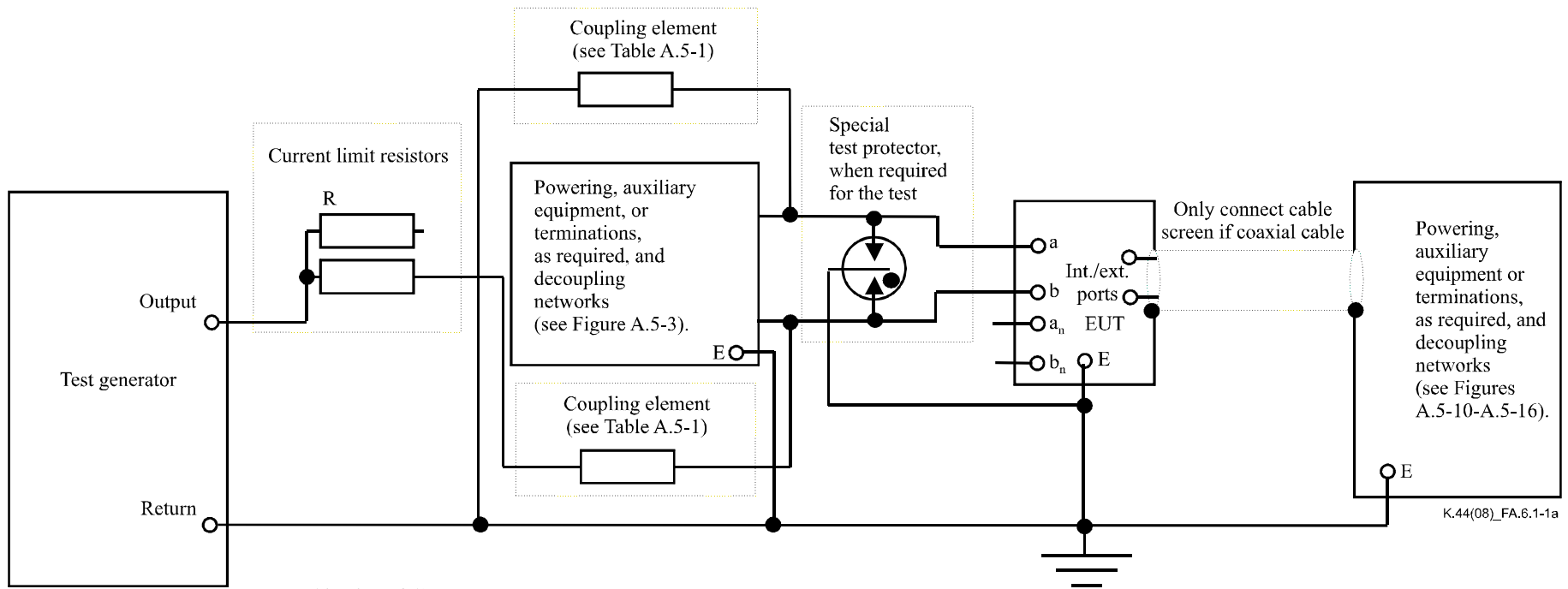
Figure A.6.4-1 gives the schematic for applying transverse surges. Figure A.6.4-2 gives the schematic for applying surges port to earth. Figure A.6.4-3 gives the schematic for applying surges from an external port to an external port.

A.6.5 Internal cable ports

See Figures A.6.5-1 and A.6.5-2.

A.6.6 d.c. power ports

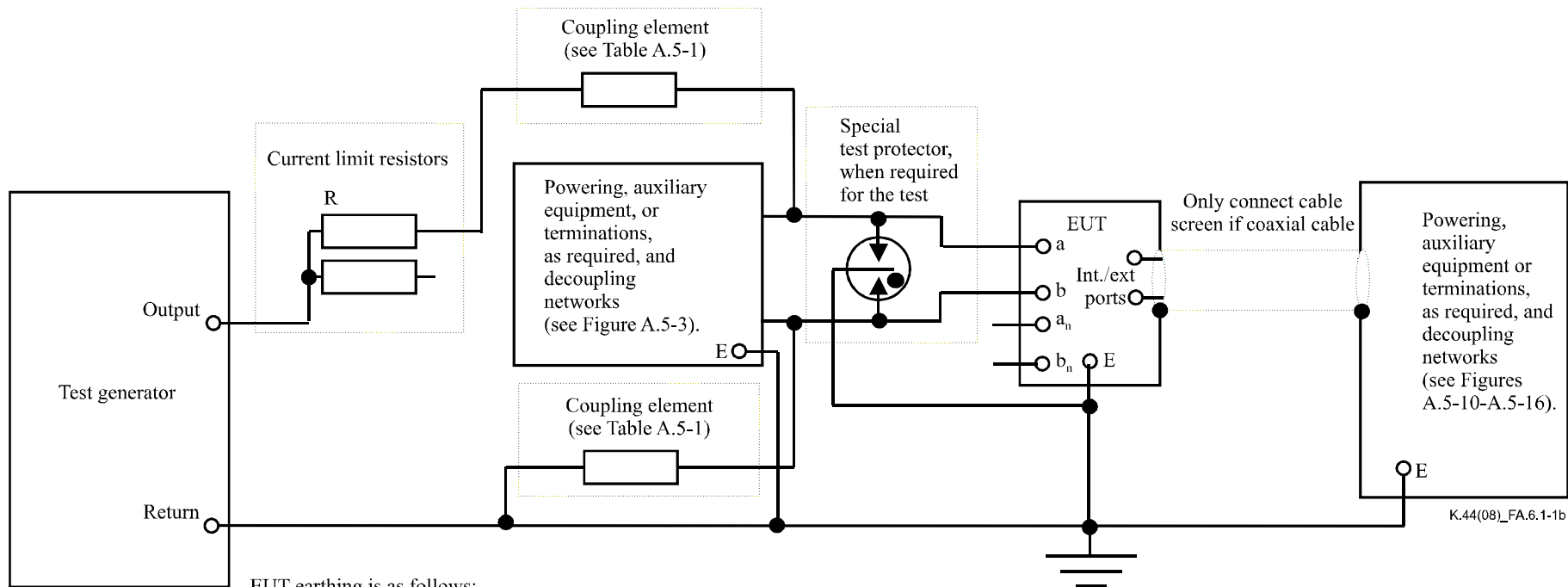
Figures A.6.6-1a and A.6.6-1b give the schematic for applying transverse surges to an EUT where one side of the power feed is earthed at the EUT. Figure A.6.6-2 gives the schematic for applying surges port to earth. The port to earth schematic is also used for internal port to internal port testing.



EUT earthing is as follows:

- 1) if the equipment has an earthing point, connect the earth to this point;
- 2) if the equipment has a conductive case but does not have an earthing point, connect the earth to the case;
- 3) if the equipment has neither an earthing point nor a conductive case, connect the earth to a ground plane.

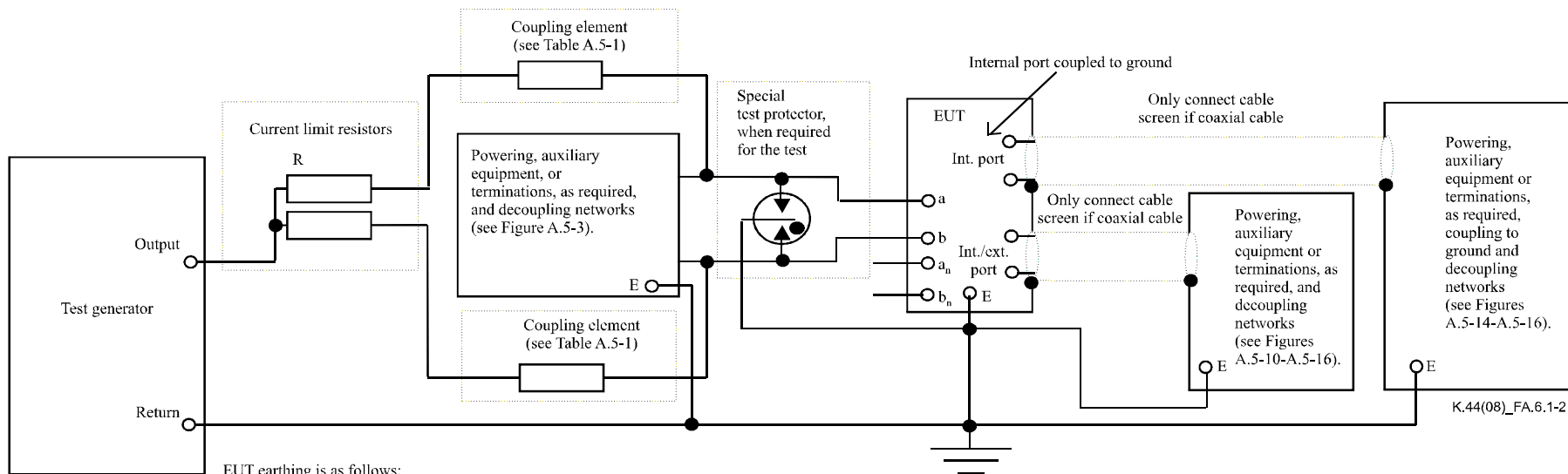
Figure A.6.1-1a – Example of a test circuit for a transverse overvoltage or overcurrent on a single external symmetric pair port (a terminal to ground)



EUT earthing is as follows:

- 1) if the equipment has an earthing point, connect the earth to this point;
- 2) if the equipment has a conductive case but does not have an earthing point, connect the earth to the case;
- 3) if the equipment has neither an earthing point nor a conductive case, let the equipment float.

Figure A.6.1-1b – Example of test circuit for a transverse overvoltage or overcurrent on a single external symmetric pair port (b terminal to ground)



EUT earthing is as follows:

- 1) if the equipment has an earthing point, connect the earth to this point;
- 2) if the equipment has a conductive case but does not have an earthing point, connect the earth to the case;
- 3) if the equipment has neither an earthing point nor a conductive case, let the equipment float.

Figure A.6.1-2 – Example of test circuit for an overvoltage or overcurrent on a single external symmetric pair port to earth

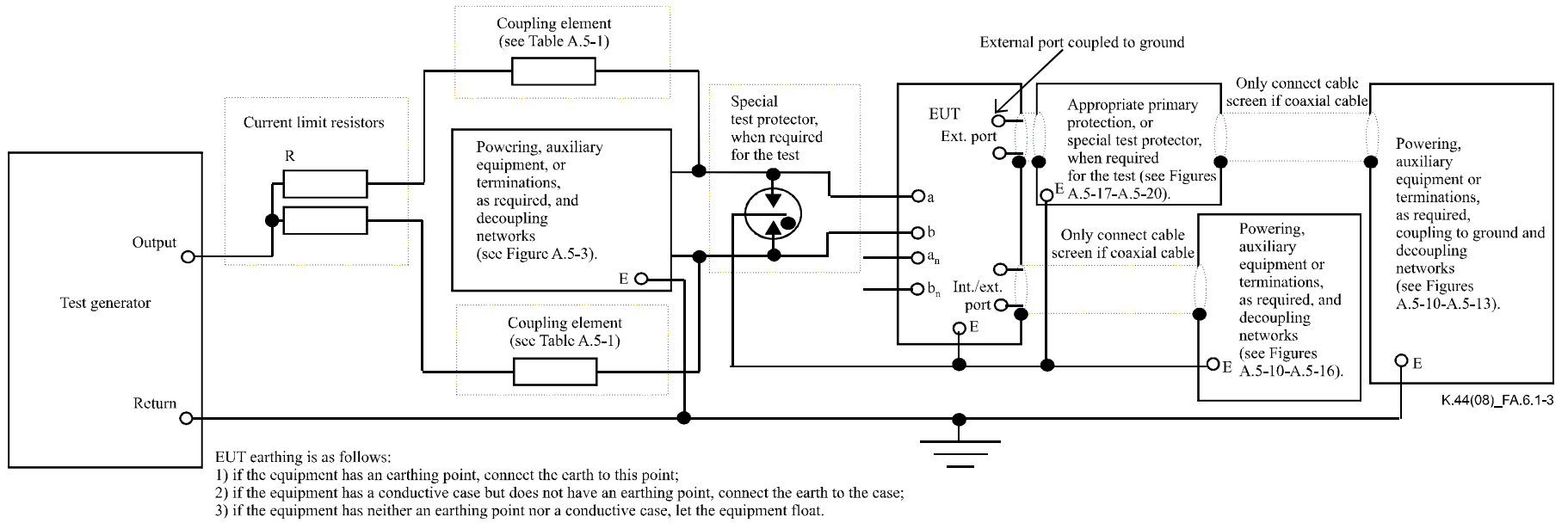
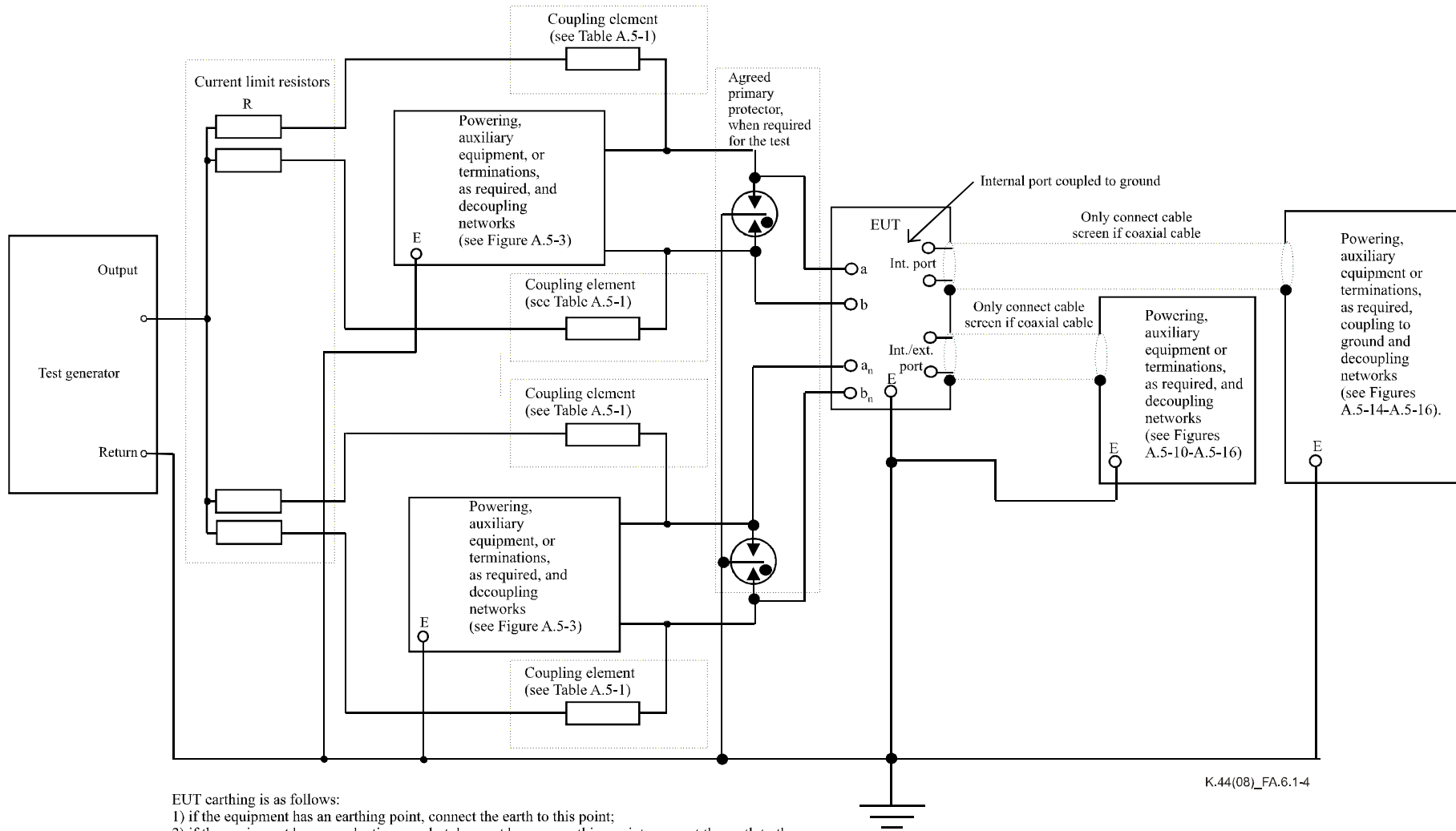
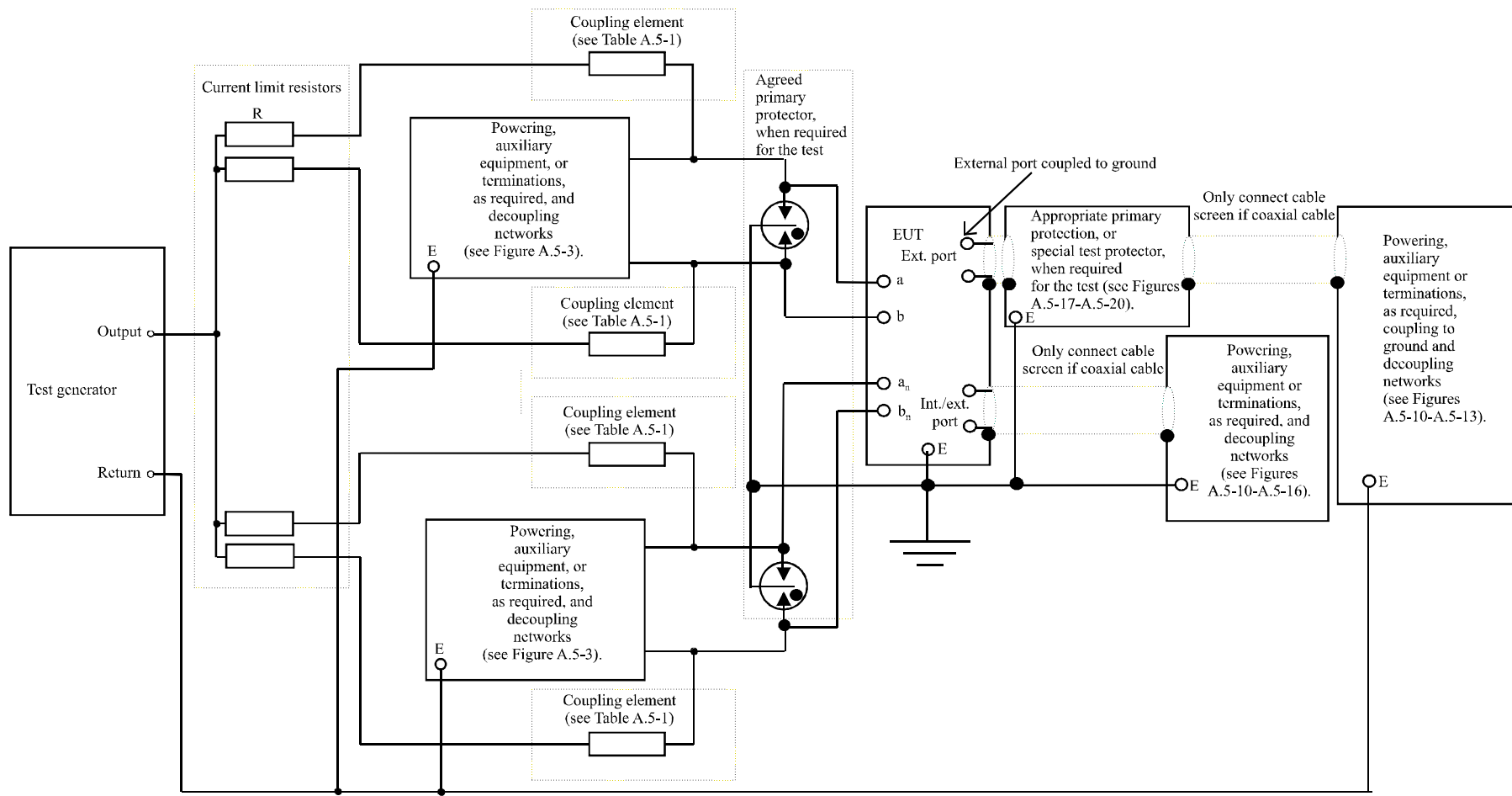


Figure A.6.1-3 – Example of test circuit for an overvoltage or overcurrent on a single external symmetric pair port to another external port



EUT earthing is as follows:
 1) if the equipment has an earthing point, connect the earth to this point;
 2) if the equipment has a conductive case but does not have an earthing point, connect the earth to the case;
 3) if the equipment has neither an earthing point nor a conductive case, let the equipment float.

Figure A.6.1-4 – Example of test circuit for an overvoltage or overcurrent on multiple external symmetric pair ports to earth



EUT earthing is as follows:

- 1) if the equipment has an earthing point, connect the earth to this point;
- 2) if the equipment has a conductive case but does not have an earthing point, connect the earth to the case;
- 3) if the equipment has neither an earthing point nor a conductive case, let the equipment float.

K.44(08)_FA.6.1-5

Figure A.6.1-5 – Example of test circuit for an overvoltage or overcurrent on multiple external symmetric pair ports to another external port

Under study

Figure A.6.2-1 – Example of a test circuit for a differential overvoltage or overcurrent on an external coaxial cable port

Under study

Figure A.6.2-2 – Example of a test circuit for a lightning shield current test on an external coaxial cable port to earth

Under study

Figure A.6.2-3 – Example of a test circuit for a lightning shield current test on an external coaxial cable port to an external port

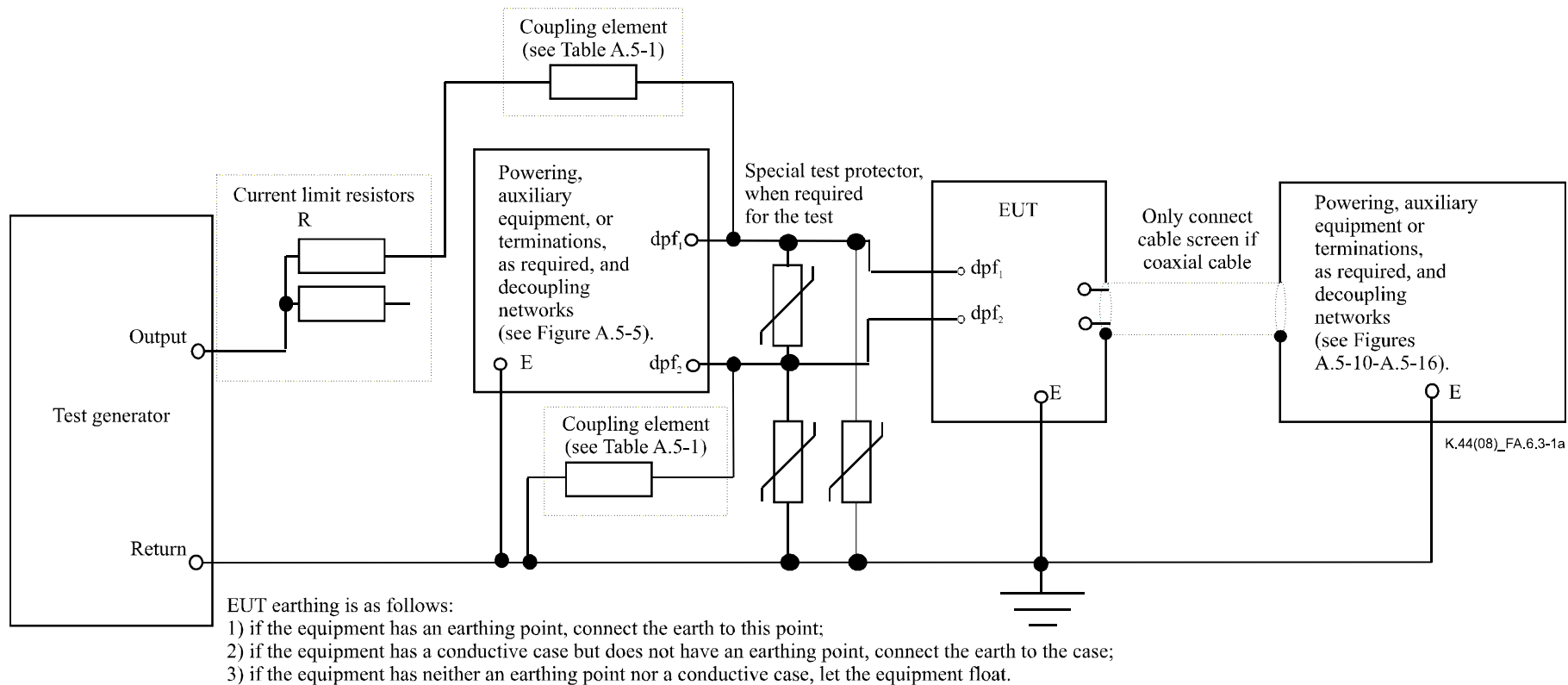


Figure A.6.3-1a – Example of test circuit for a transverse overvoltage or overcurrent on a single external dpf port (dpf₂ grounded)

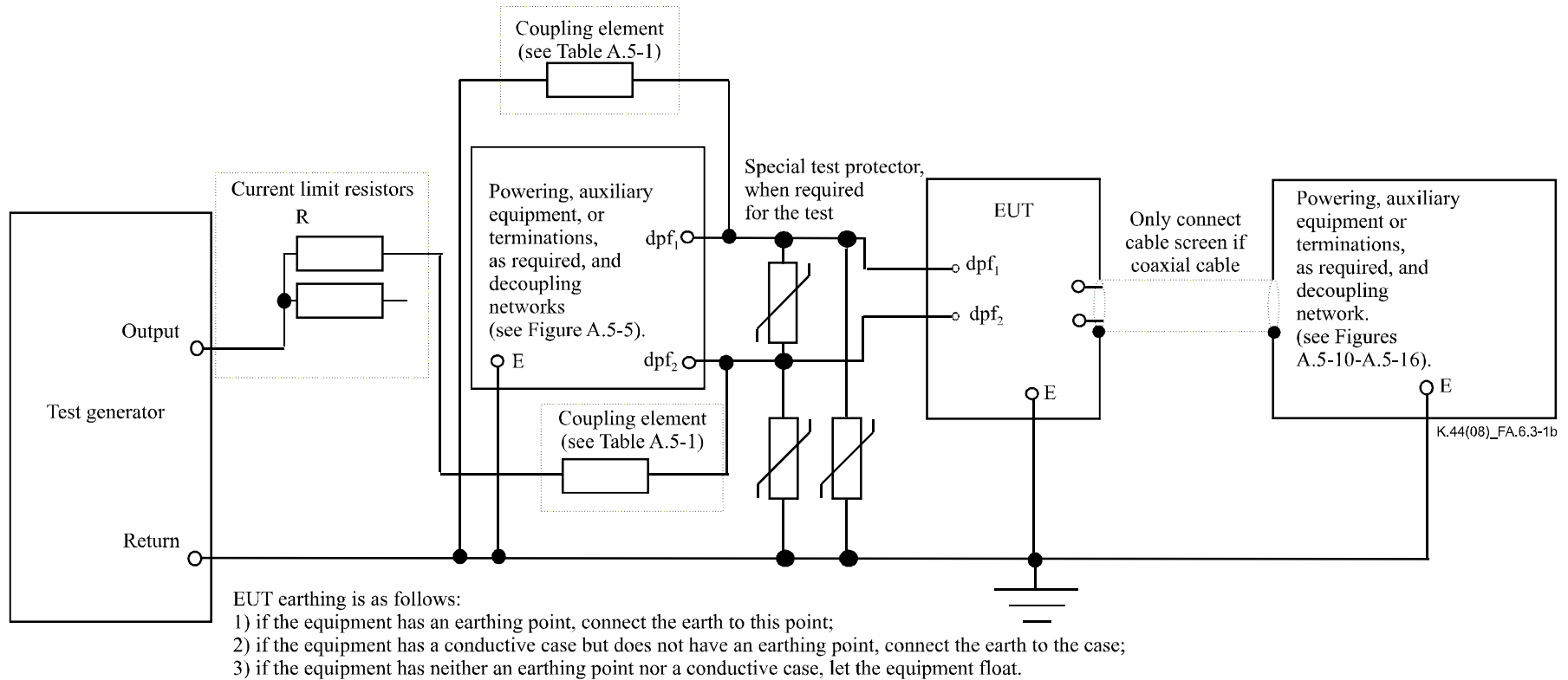
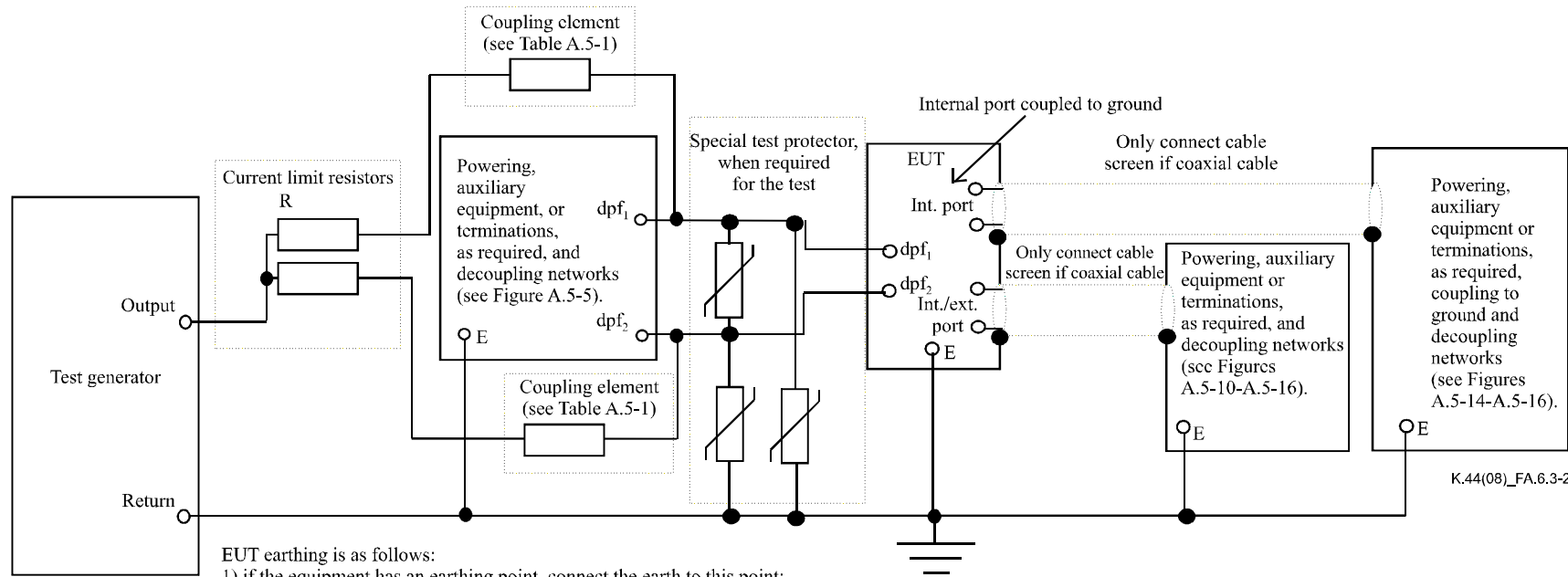


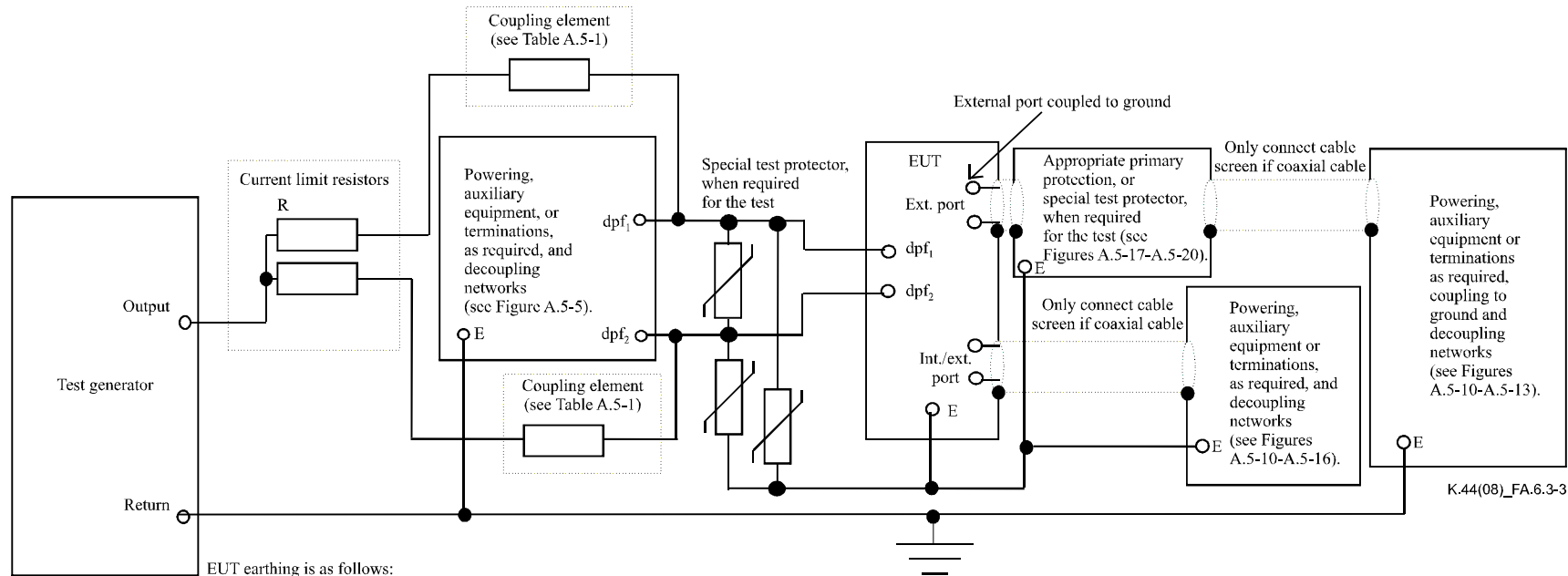
Figure A.6.3-1b – Example of test circuit for a transverse overvoltage or overcurrent on a single external dpf₁ port (dpf₁ grounded)



EUT earthing is as follows:

- 1) if the equipment has an earthing point, connect the earth to this point;
- 2) if the equipment has a conductive case but does not have an earthing point, connect the earth to the case;
- 3) if the equipment has neither an earthing point nor a conductive case, let the equipment float.

Figure A.6.3-2 – Example of test circuit for an overvoltage or overcurrent on a single external dpf port to earth



K.44(08)_FA.6.3-3

- EUT earthing is as follows:
- 1) if the equipment has an earthing point, connect the earth to this point;
 - 2) if the equipment has a conductive case but does not have an earthing point, connect the earth to the case;
 - 3) if the equipment has neither an earthing point nor a conductive case, let the equipment float.

Figure A.6.3-3 – Example of test circuit for an overvoltage or overcurrent on a single external dpf port to external port

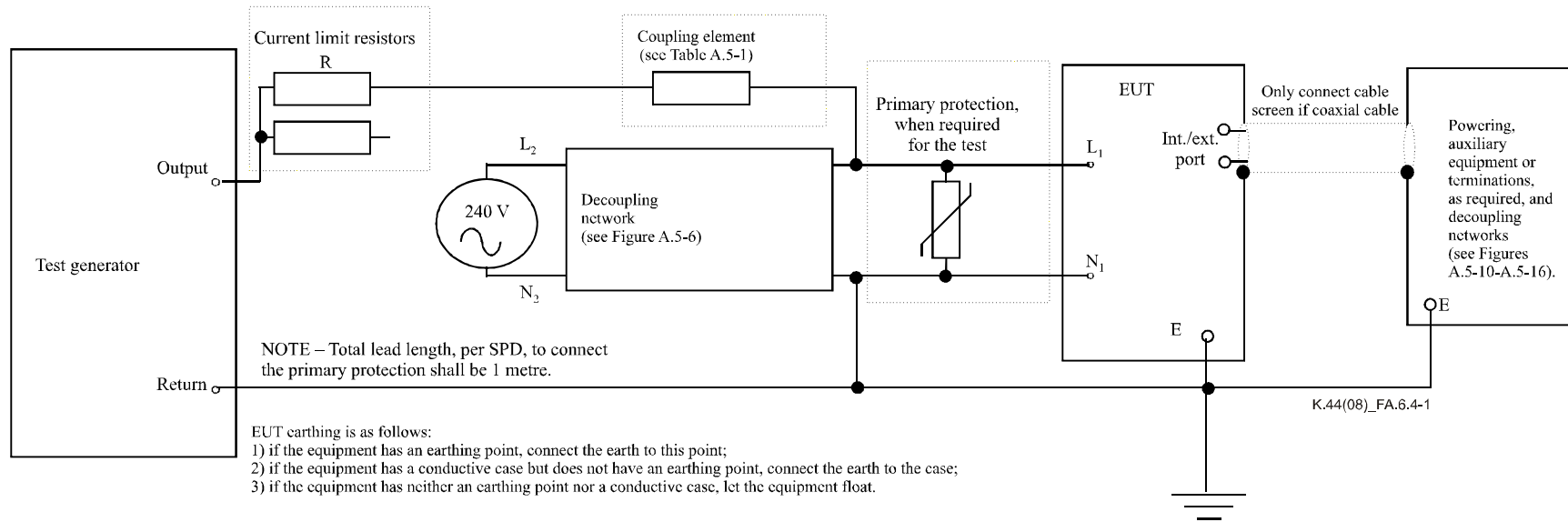


Figure A.6.4-1 – Example of test circuit for a transverse overvoltage or overcurrent on an external mains port

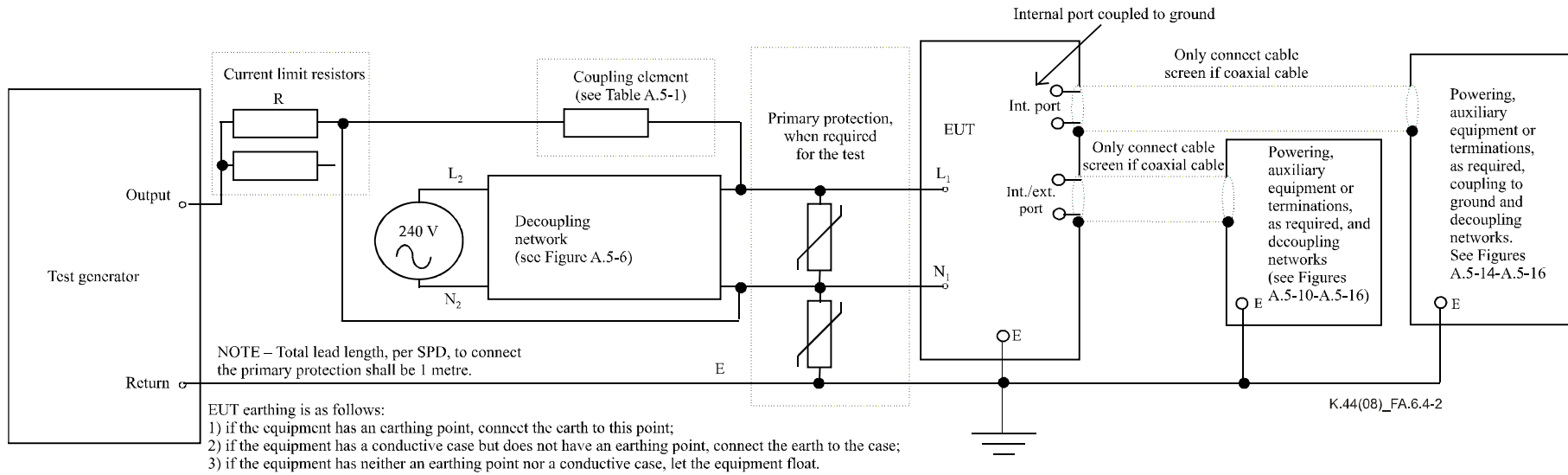


Figure A.6.4-2 – Example of test circuit for an overvoltage, overcurrent and rise of neutral potential on an external mains port to earth

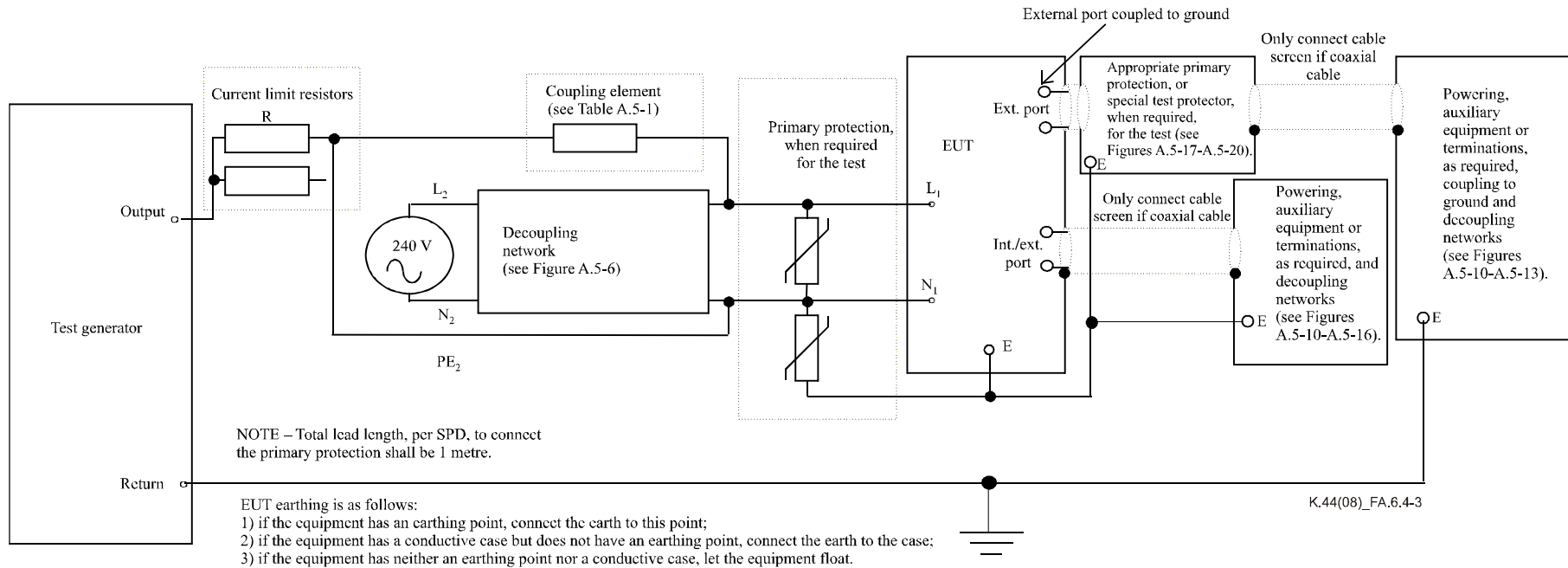
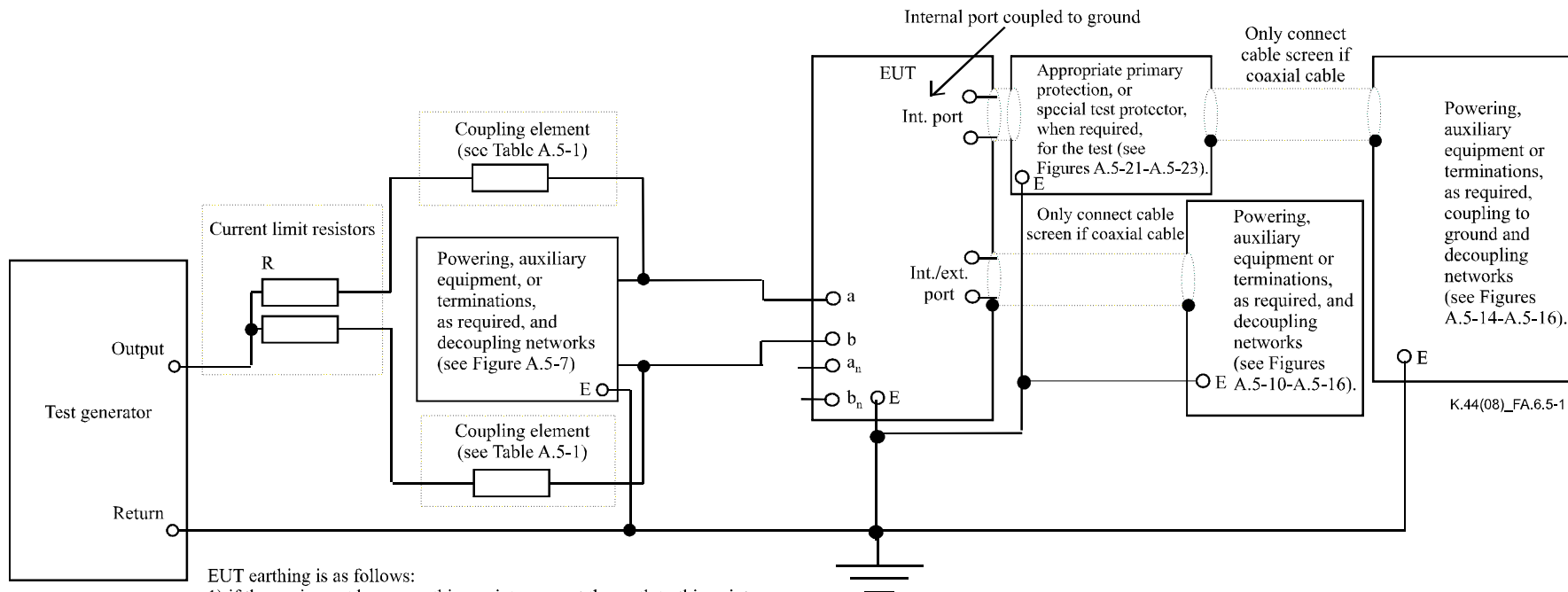


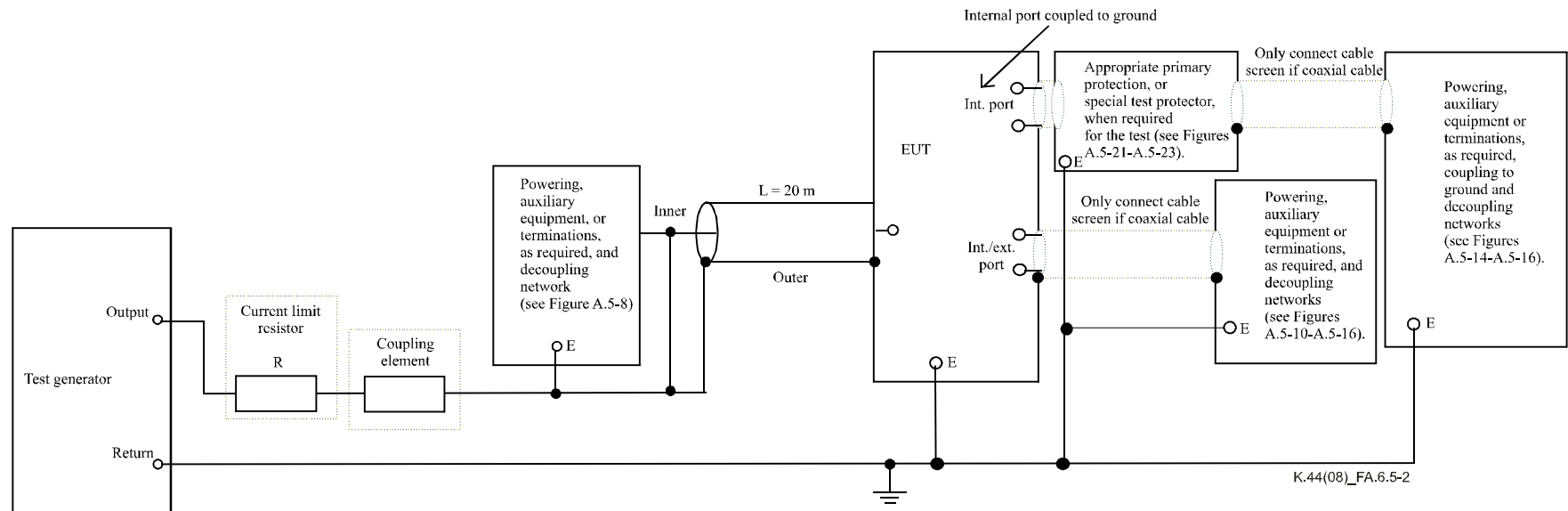
Figure A.6.4-3 – Example of test circuit for an overvoltage, overcurrent and rise of neutral potential on an external mains port to external port



EUT earthing is as follows:

- 1) if the equipment has an earthing point, connect the earth to this point;
- 2) if the equipment has a conductive case but does not have an earthing point, connect the earth to the case;
- 3) if the equipment has neither an earthing point nor a conductive case, let the equipment float.

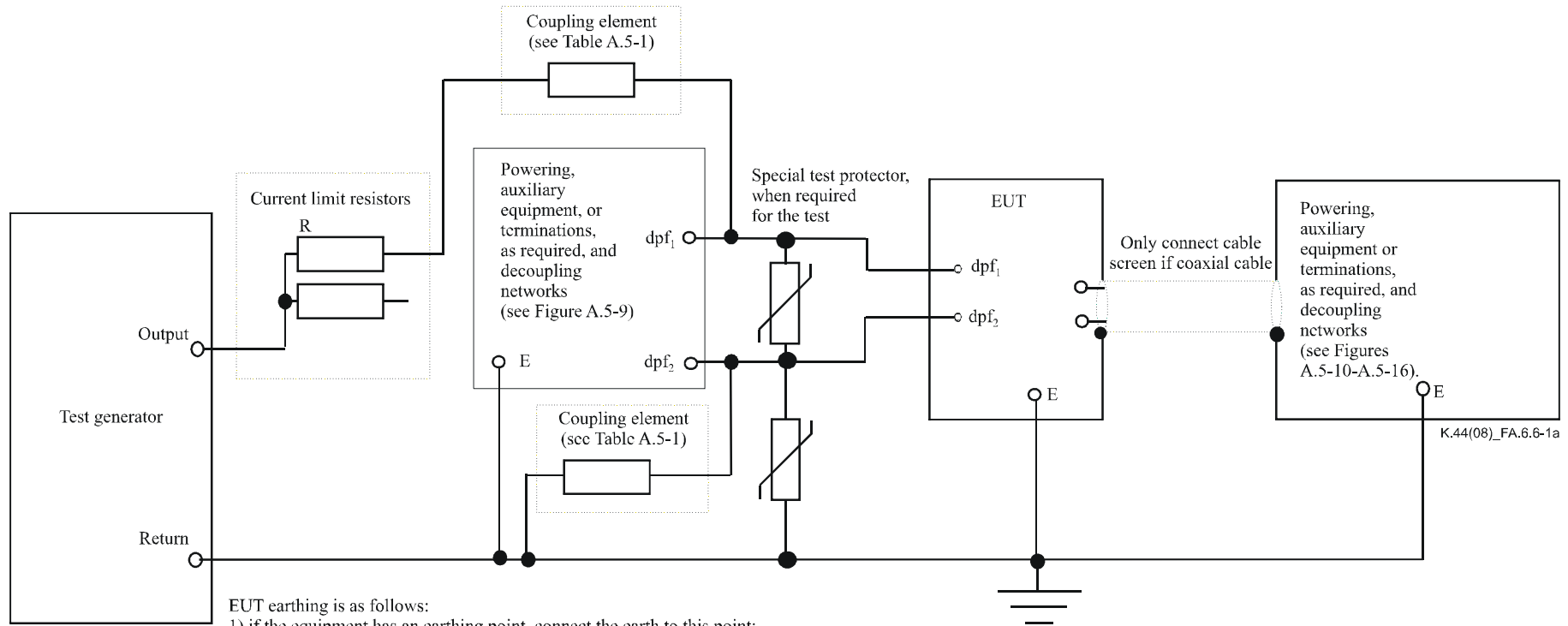
Figure A.6.5-1 – Example of a test circuit for a port to earth overvoltage or overcurrent on a single pair unshielded internal symmetric pair cable port



For repeatability of measurement, it is recommended that the test be performed on an earth reference plane, with the cable laid on the ground plane in a snake pattern. All conductors are connected together and with the shield (reason: in the worst case, inserted protective elements in the auxiliary equipment – not included in this test set-up – can cause short-circuit termination).

- EUT earthing is as follows:
- 1) if the equipment has an earthing point, connect the earth to this point;
 - 2) if the equipment has a conductive case but does not have an earthing point, connect the earth to the case;
 - 3) if the equipment has neither an earthing point nor a conductive case, let the equipment float.

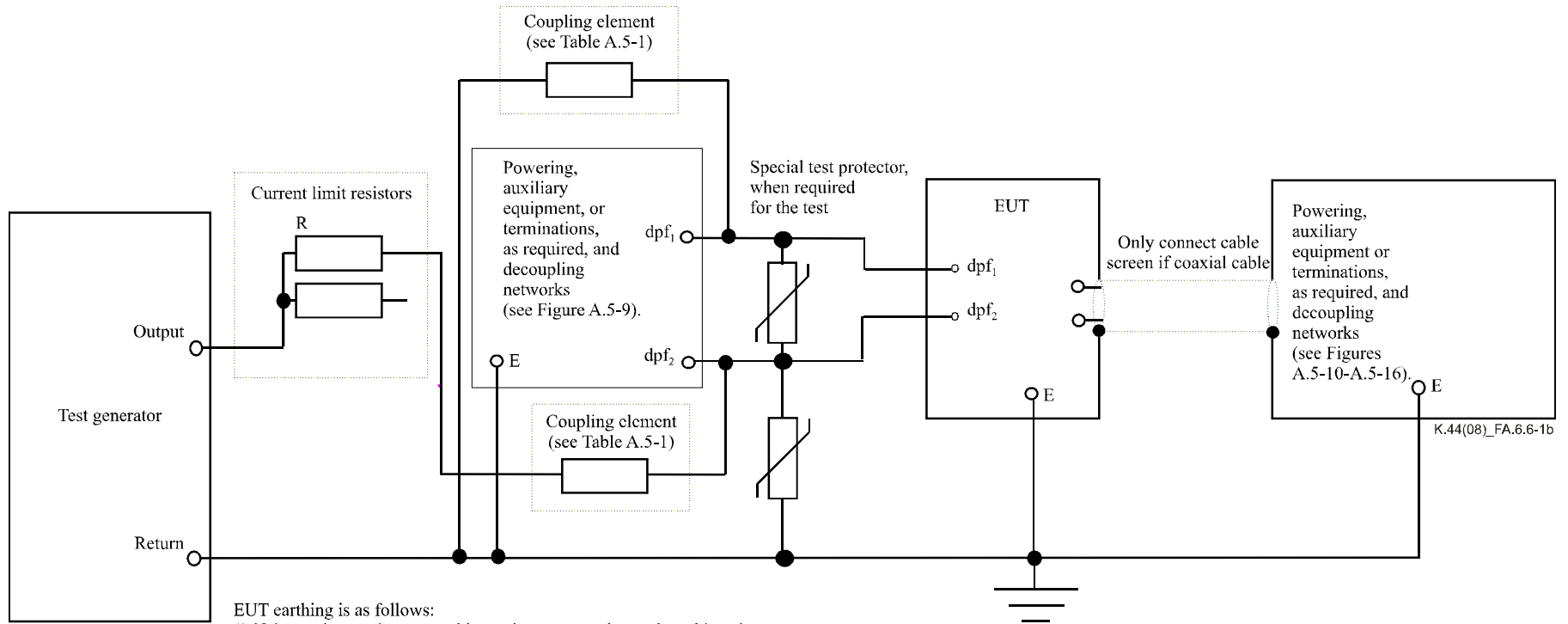
Figure A.6.5-2 – Example of test circuit for internal shielded cable ports



EUT earthing is as follows:

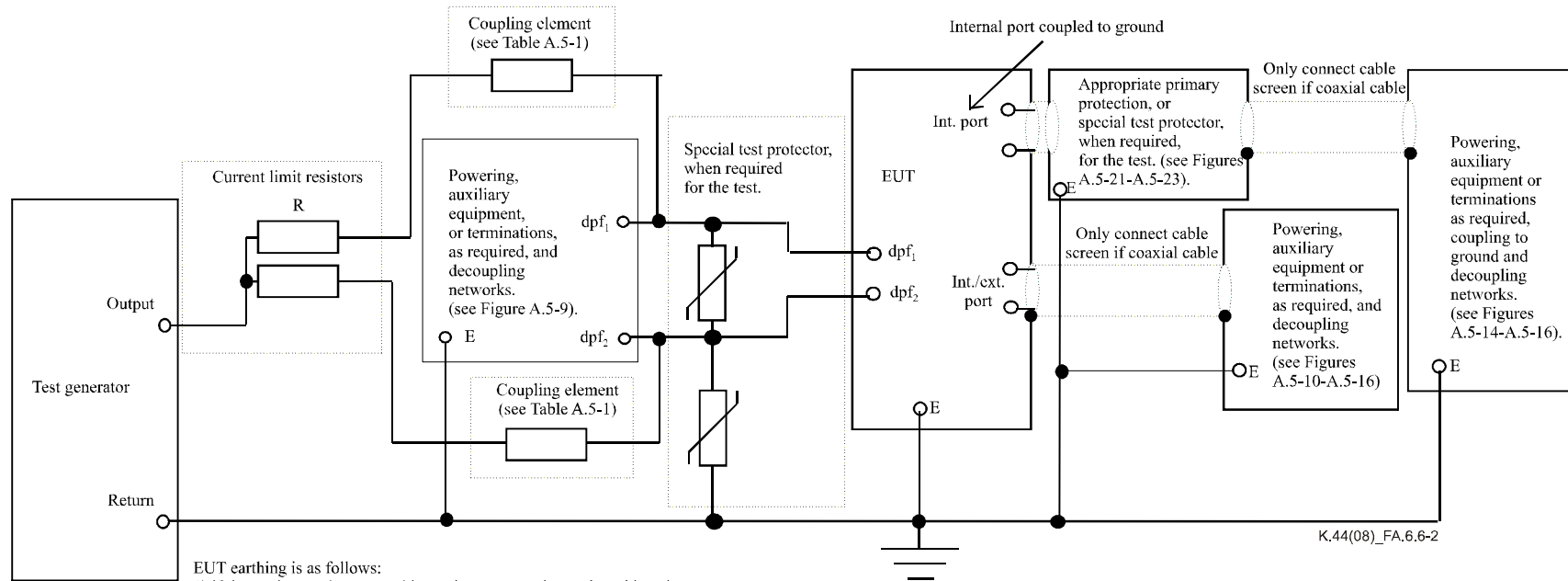
- 1) if the equipment has an earthing point, connect the earth to this point;
- 2) if the equipment has a conductive case but does not have an earthing point, connect the earth to the case;
- 3) if the equipment has neither an earthing point nor a conductive case, let the equipment float.

Figure A.6.6-1a – Example of test circuit for a transverse overvoltage or overcurrent on a single internal d.c. power port (dpf_2 grounded)



EUT earthing is as follows:
 1) if the equipment has an earthing point, connect the earth to this point;
 2) if the equipment has a conductive case but does not have an earthing point, connect the earth to the case;
 3) if the equipment has neither an earthing point nor a conductive case, let the equipment float.

Figure A.6.6-1b – Example of test circuit for a transverse overvoltage or overcurrent on a single internal d.c. power port (dpf₁ grounded)



EUT earthing is as follows:
 1) if the equipment has an earthing point, connect the earth to this point;
 2) if the equipment has a conductive case but does not have an earthing point, connect the earth to the case;
 3) if the equipment has neither an earthing point nor a conductive case, let the equipment float.

Figure A.6.6-2 – Example of test circuit for an overvoltage or overcurrent on a single internal d.c. power port to earth

Appendix I

Explanations that illustrate test conditions

(This appendix does not form an integral part of this Recommendation)

I.1 Testing

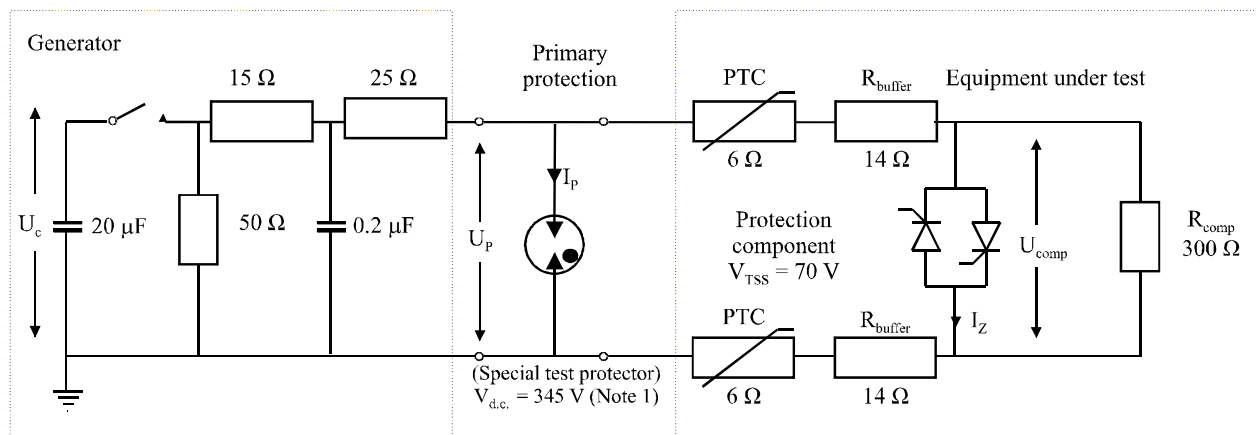
I.1.1 General

To check that the equipment fulfils the specified acceptance criteria for all voltage and current levels up to the maximum test level, it is necessary to either test at a large range of test voltages/currents from zero to the maximum level specified, or to perform "intelligent testing". Clauses I.1.2-I.1.4 provide information on intelligent testing which minimizes the number of test levels but ensures that sufficient tests are performed.

I.1.2 Lightning surge tests

To check that no damage windows exist within the equipment, it is necessary to perform tests at specific test voltages. These specific test voltages are determined by the operating points of such components as the primary protector (GDT or SSA) and switching protective devices within the equipment. Examples of these test voltages are illustrated using an example of a linecard with a $6\ \Omega$ PTC and a $14\ \Omega$ resistor in series ($20\ \Omega$ in total) and with a shunt switching type inherent protector. This example linecard, along with the test generator and the primary protector, is shown in Figure I.1-1. Apart from the test generator, all the circuit layout and component values have been chosen only for explanatory purposes and are not put forward as recommended practice.

When the charging voltage U_c is progressively raised, the different components are subjected to different voltages, currents and energies.



K.44(08)_FI.1-1

NOTE 1 – Special test protector for 230 V primary protector.

NOTE 2 – In practice, the total resistance of R_{buffer} + the PTC may vary from 10-100 Ω and R_{comp} may also have different values.

Figure I.1-1 – Example linecard with designated voltages and currents

The above circuit is an example of a linecard with a low input impedance when the inherent protection operates. The equipment is nominally protected in exposed areas with an SSA or a GDT on the MDF. It is assumed that it will be protected with a 230 V GDT and the primary protector has been replaced with a GDT with a 345 V d.c. sparkover voltage as described in clause 8.4.1 (i.e.,

300 V_{dcmx} multiplied by 1.15). The circuit shown is for a transverse test, see Figure A.6.1-1a. To keep the circuit simple, no coupling or decoupling elements, or auxiliary equipment, have been shown. The figures shown are for positive polarity surges only. The 300 Ω resistor R_{comp} represents the transverse impedance of the components to be protected.

R_{buffer} is an additional resistor. The value of the total resistance of R_{buffer} + the PTC may vary in practice from 10 to 100 Ω. This resistor, in conjunction with the PTC, provides a buffer impedance between the primary protection and the inherent protection to achieve coordination. The input impedance (resistance) of the EUT when inherent protection turns on is 2*(6 + 14). In some applications, it is possible that the PTCs and resistors R_p will be at the MDF with the primary protection. Note that having PTCs and resistors R_p at the MDF is not a recommended practice as some operators may have MDFs that do not accept series impedance. Also, it is better for the PTCs to be at the temperature of the linecard. However, there may be some circumstances where PTCs or other types of overcurrent protection need to be installed on the MDF (see [ITU-T K.30] for guidance).

R_{comp} is the resistance of the circuit. Its value may vary with current and frequency. However, it is usual that the maximum current which flows through R_{comp} is less than 0.2 A. This current is negligible compared to the current, which is conducted by the inherent protection when it operates.

The inherent protection is a PNP type device.

To thoroughly test the resistibility of the equipment, it is necessary to test the equipment at a number of different values for U_c.

I.1.2.1 Inherent test

The value of U_c is given in the product Recommendation. The generator is set to apply the required surges.

I.1.2.2 Secondary protector coordination test

If the equipment contains a switching type inherent protector, e.g., a thyristor, the value of U_c is adjusted to generate a surge just less than that which will turn on the switching type protector. In the example linecard, the thyristor will turn on if the voltage across it exceeds its switching voltage, usually around 70 V. After the thyristor turns on, the voltage drop is only 1 or 2 V.

A U_c of 90 V produces 69 V across R_{comp} and no current flows in the thyristor, see Figure I.1-2. This is the point of worst stress for the components and 10 surges of alternate polarity should be applied.

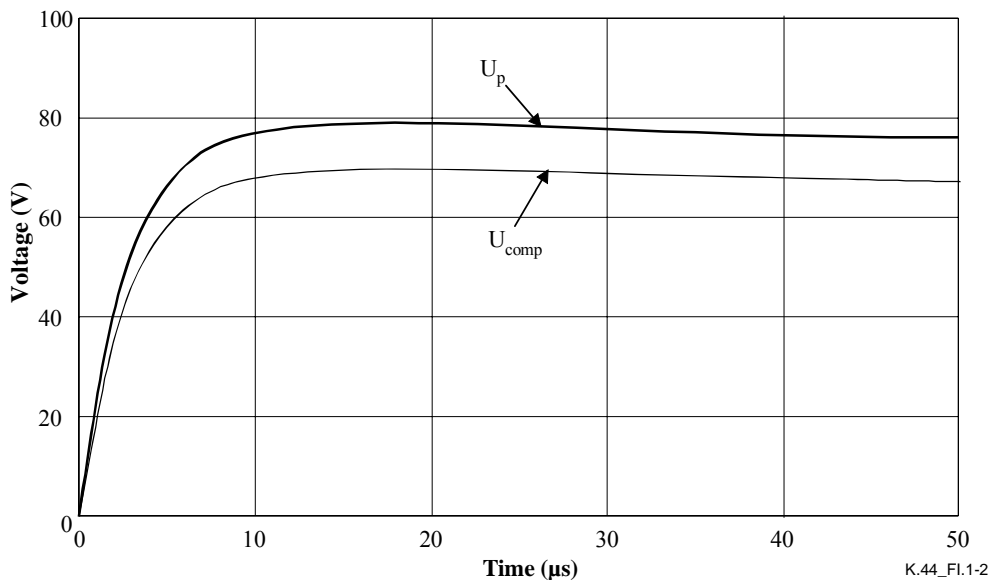


Figure I.1-2 – Voltages with U_c to give a U_{comp} of 69 V

With a U_c of 92 V, the voltage across R_{comp} exceeds 70 V, the inherent protection operates and current is conducted through the PTCs and the 14 Ω resistors, see Figure I.1-3. This will limit the voltage across the components to be protected to 70 V.

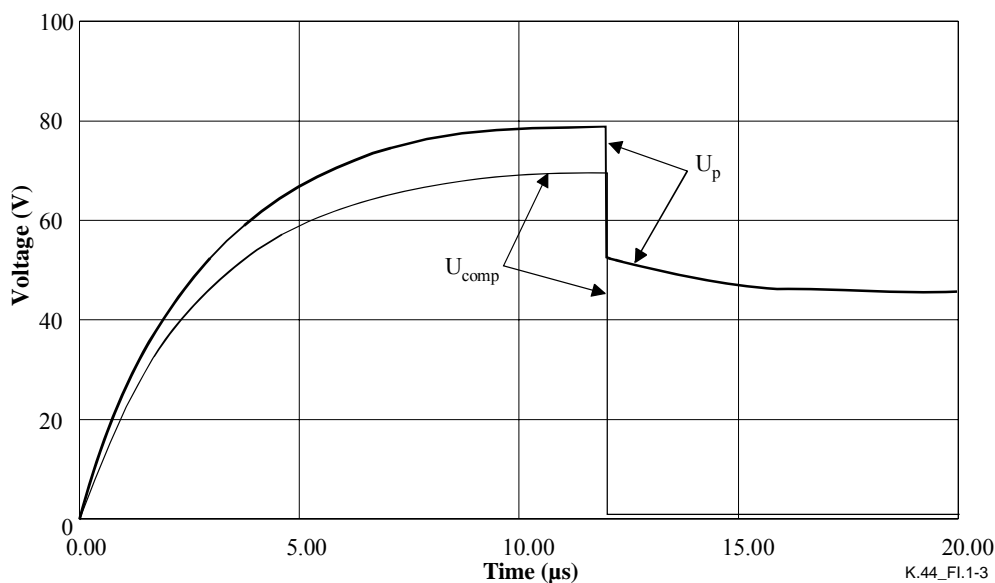


Figure I.1-3 – Voltages with U_c to give a U_{comp} of 70 V

I.1.2.3 Primary protector coordination test

If the equipment will be protected by a switching type primary protector, e.g., a GDT, the value of U_c is adjusted to generate a surge just less than that which will turn on the switching type protector. By increasing charging voltage U_c the voltage across the PTCs and the 14 Ω resistors, and the current through the PTCs and the resistors, will increase until the charging voltage is just below the activation level of the primary protection, see Figure I.1-4. In the example linecard, a charging voltage, U_c , of 843 V is the point of maximum stress for the PTCs and the 14 Ω resistors, and 10 surges of alternate polarity should be applied. Figure I.1-4 shows the maximum full wave 10/700 μ s voltage which appears at the input of the equipment.

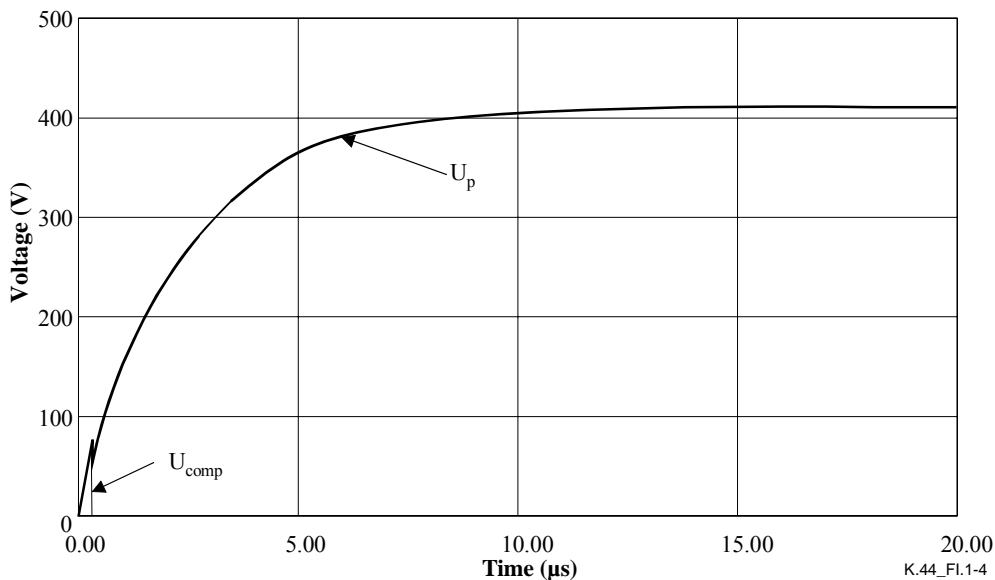


Figure I.1-4 – Voltages with U_c set to cause a U_p just below the sparkover voltage of the GDT

With a U_c of 855 V, the primary protection is activated, the voltage U_p drops to a lower value (typically about 25 V). The current I_z flowing into the equipment falls to a very low value and becomes practically independent of U_c .

Figure I.1-5 shows the measured voltage U_p across the primary protection and the voltage across the PTCs and the 14 Ω resistors for a charging voltage U_c of 855 V and a GDT with a d.c. breakdown voltage of 345 V, the firing voltage of the special test protector used when the agreed primary protector is a 230 V GDT. The different currents can be calculated from the voltages. The primary protector used was activated after 15 μ s and the maximum voltage across the GDT was 420 V.

It should be noted that if the primary protection is not activated during the rising edge, it can still be activated during the decay period as the voltage remains initially almost constant during the decay period. When the GDT is activated during the decay period, the breakdown voltage is lower and approaches the d.c. breakdown voltage.

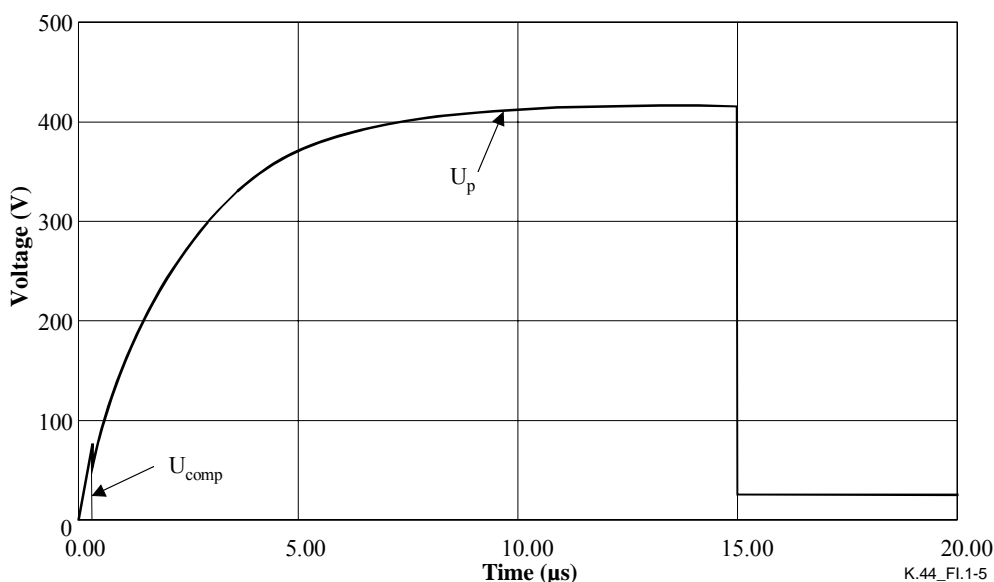


Figure I.1-5 – Voltage U_p across the special test protector for a charging voltage U_c of 855 V

I.1.2.4 $U_{c(max)}$ test

Figure I.1-6 shows the measured voltage U_p across the primary protection and the voltage across the PTCs and the 14 Ω resistors for a charging voltage U_c of 4 kV. The primary protection was activated after 1.5 μs and the maximum voltage across the GDT is 632 V. Although the voltage is higher, the amount of energy that is passed to the equipment is lower.

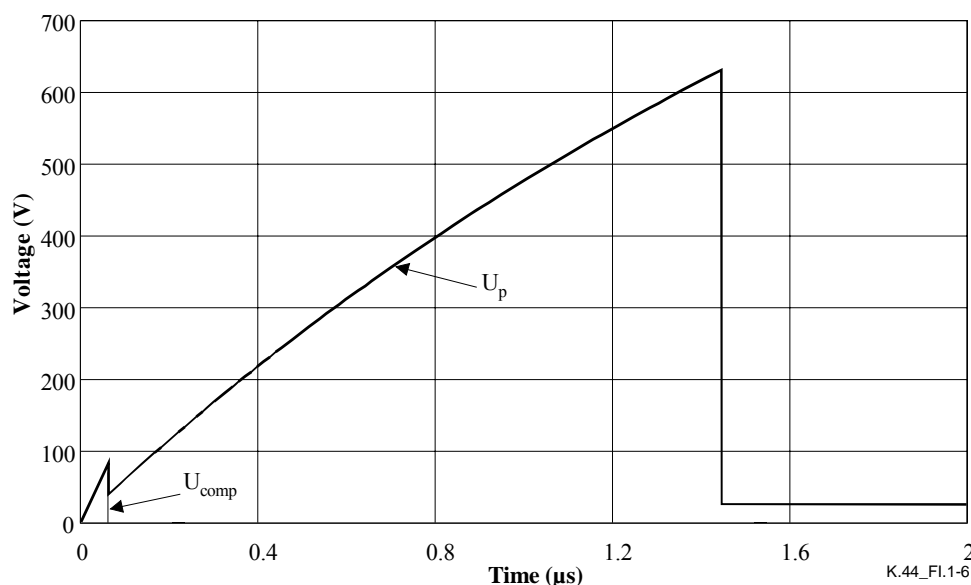


Figure I.1-6 – Voltage U_p across the special test protector for a charging voltage U_c of 4 kV

I.1.2.5 Effects for greater than $U_{c(max)}$

Figure I.1-7 shows the measured voltage U_p across the primary protection and the voltage across the PTCs and the 14 Ω resistors for a charging voltage U_c of 10 kV. The primary protection was activated after 0.5 μs and the maximum voltage across the GDT is 690 V. Although the voltage is higher, the amount of energy that is passed to the equipment is lower.

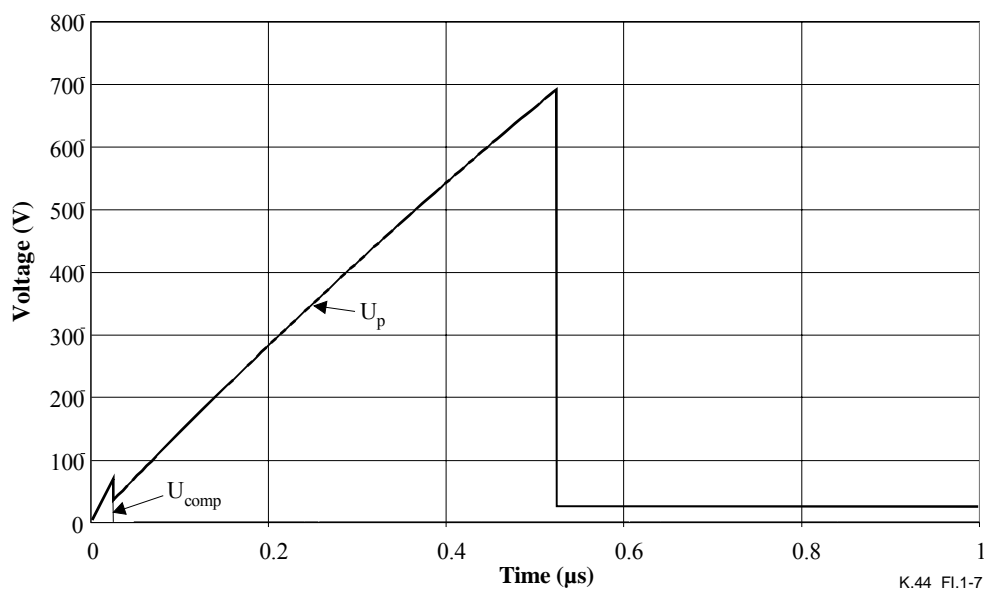


Figure I.1-7 – Voltage U_p across the special test protector for a charging voltage U_c of 10 kV

This example with six different charging voltages shows the importance of the knowledge of the characteristics of the primary protection and the inherent protection in order to assure a proper coordination between primary and inherent protection, and the equipment.

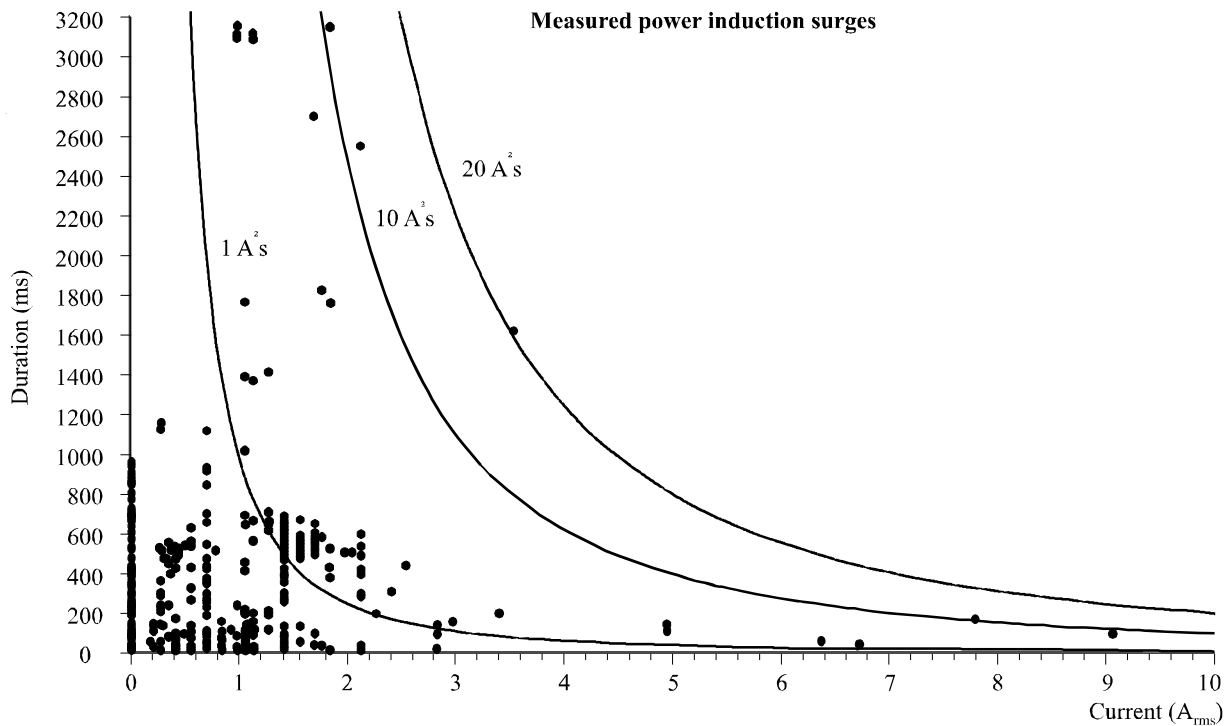
I.1.3 Power induction

Induced voltages are more likely to occur on long lines, and in the common case where customers' lines do not provide a low resistance to earth, induced voltages E may be considered to have a high source impedance consisting of a 600Ω wire resistance in series with a $0.33 \mu\text{F}$ line to earth capacitance as shown in Figure I.1-9. The telephone is represented by a 100Ω resistance and the hook-switch. The GDTs shown in Figure I.1-9 are needed only on lines in exposed areas. However, because of the liberalization of CPE, such protectors may also be present on less-exposed lines. These GDTs fire at the customer line end in the short-term power induction case and short-circuit the telephone and the line capacitances. Therefore, the test circuit given in Figure A.3-6 consists only of the induced voltage $E = U_{a.c.}$ and the wire resistances R .

Field experience showed that a large number of linecards in some exchanges were damaged by power induction during thunderstorm days. The damage appeared only in exposed rural areas. The currents induced on such lines, and causing the linecard damage, were measured in a few cases and showed values between 4 and 6 A and duration between 200 and 500 ms, i.e., I^2t values up to 10-20 A^2s . Figure I.1-8 shows measurements of power induction in Australia.

These overcurrents with high I^2t values were estimated as rare events; therefore, it was agreed that the induction test, with agreed primary protection, should simulate an overcurrent with a I^2t of 1 A^2s for the basic requirement and 10 A^2s for the enhanced requirement.

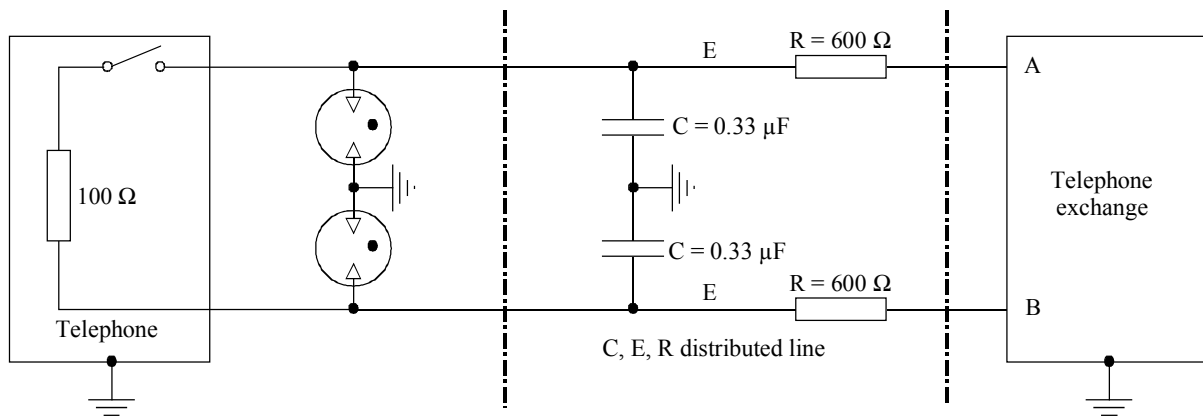
Considering that most test laboratories only had available a test circuit with a maximum test voltage of 600 V, it was decided to define, for the basic requirement induction test, this maximum voltage value $U_{a.c.(\text{max})} = 600 \text{ V}$ and to increase the test duration up to 1 s.



NOTE – Surges of 0 A were less than minimum current resolution.

K.44_FI.1-8

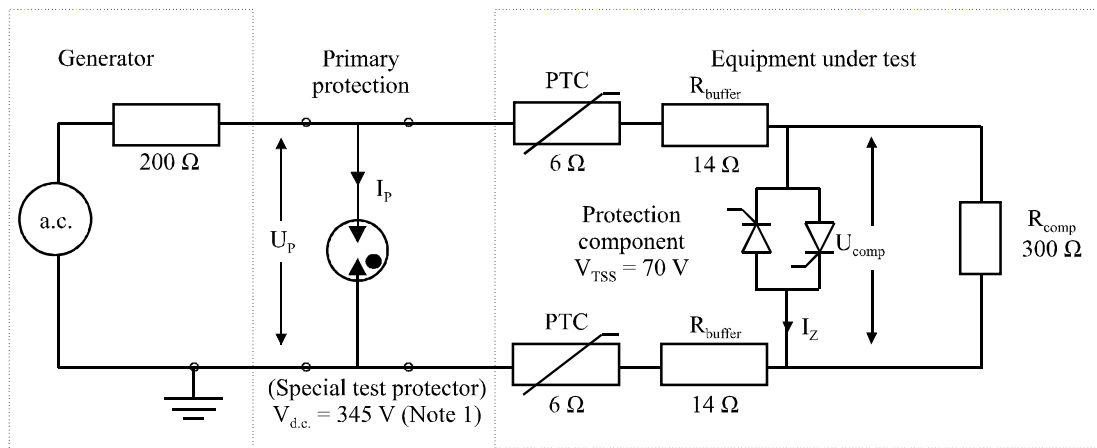
Figure I.1-8 – Power induction overcurrents measured in Australia



K.44_FI.1-9

Figure I.1-9 – Equivalent circuit of a telecommunication line during power induction

As with the lightning surge testing, it is also necessary to be aware of the need to test at specific voltage levels when performing power induction tests. An example of a linecard circuit utilizing a PTC and switching protector is shown in Figure I.1-10. During testing, the following points were monitored, U_p , I_p , U_{comp} and I_z , to illustrate the operation of various components. The monitoring internal to the equipment was done to help designers and testers to understand the issues to consider when testing the equipment. It is not necessary to monitor internal to the equipment during type approval testing.



K.44(08)_FI.1-10

NOTE 1 – Special test protector for 230 V primary protector.

NOTE 2 – In practice, the total resistance of R_{buffer} + the PTC may vary from 10-100 Ω and R_{comp} may also have different values.

Figure I.1-10 – Example circuit

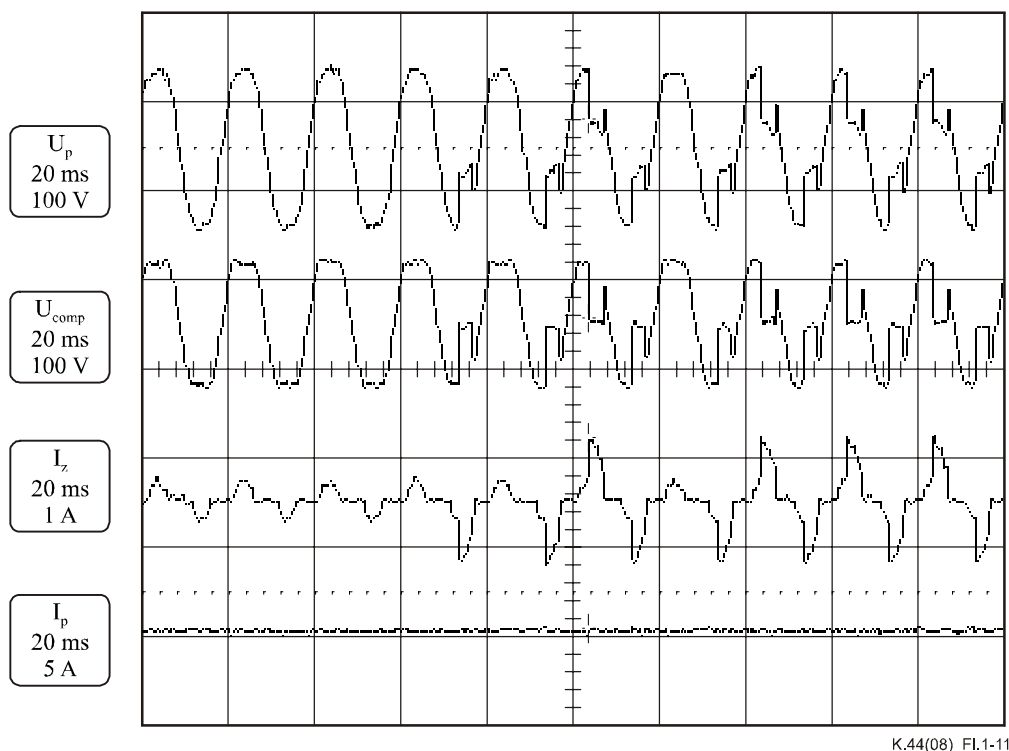
As with the lightning surge testing, power induction testing has to be performed at specific test levels.

I.1.3.1 Inherent test

The value of $U_{\text{a.c.}}$ and the duration is given in the product Recommendation. The generator is set to apply the required surges.

I.1.3.2 Secondary protector coordination test

If the equipment contains a switching type inherent protector, e.g., a thyristor, the value of $U_{\text{a.c.}}$ is adjusted to generate a surge just less than that which will turn on the switching type protector. As the test voltage is increased from zero volts, it is noticed that the switching devices start to operate at the peak of the voltage, see Figure I.1-11. This may be due to a marginal increase in the generator voltage. A generator voltage just below that which operates the inherent protection for switching and foldback type inherent protection is the point of maximum voltage stress for the components to be protected. Five surges should be applied with the generator voltage set just below that which operates the inherent protection.

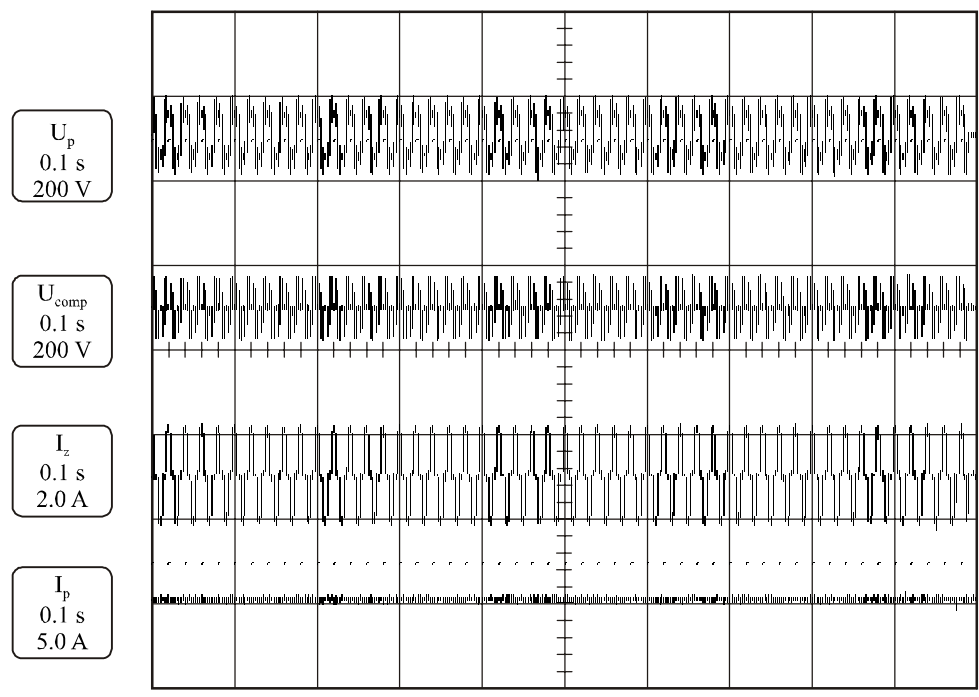


K.44(08)_FI.1-11

Figure I.1-11 – $U_{a.c.} = 127 V_{rms}$, switching inherent protector starts to operate

I.1.3.3 Secondary protector operating test

If the voltage is increased further, it is noticed that the switching devices operate for the whole test period, but there is insufficient heating of the PTC to cause it to operate, see Figure I.1-12. Five surges should be applied with this generator voltage. This test applies whether there are PTCs or not.



K.44(08)_FI.1-12

Figure I.1-12 – $U_{a.c.} = 200 V_{rms}$, switching inherent protector operating, but not PTC

I.1.3.4 Minimum energy to operate PTCs

This test only applies to equipment with PTCs. As $U_{a.c.}$ is increased further, the PTC operates at the end of the test period. In some cases, the value of $U_{a.c.}$ may not be high enough to operate the special test protector, see Figure I.1-13. Five surges should be applied with this generator voltage.

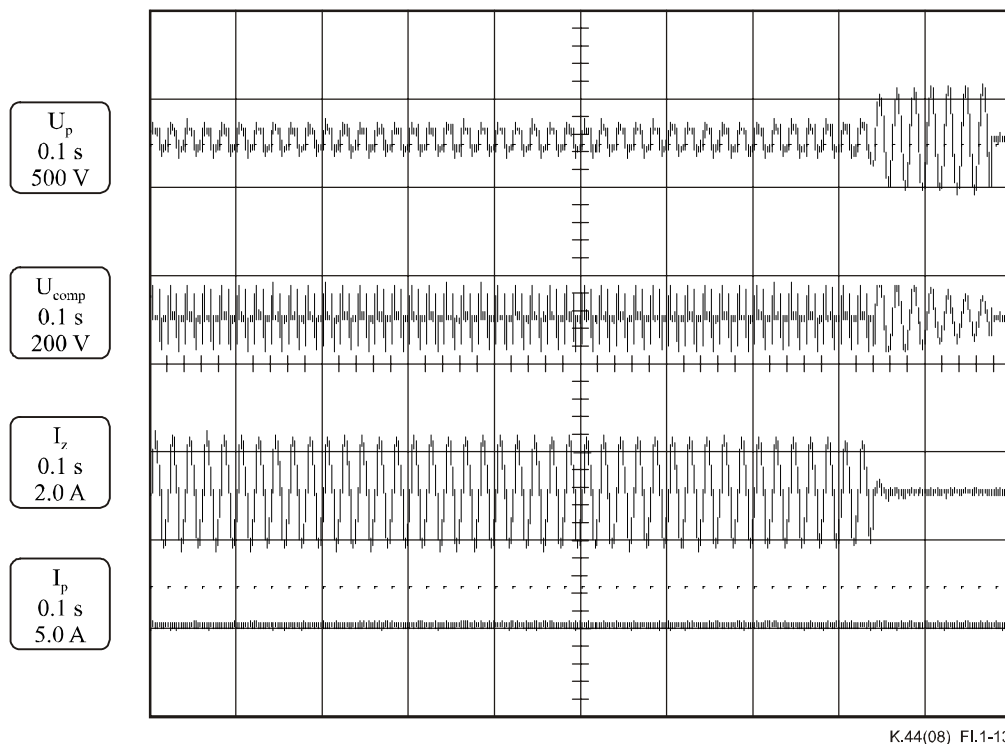


Figure I.1-13 – $U_{a.c.} = 220 V_{rms}$, PTC operates at end of test (2 s), below firing voltage of special test protector

I.1.3.5 Primary protector coordination test

I.1.3.5.1 Primary protector coordination test for equipment without PTCs

As $U_{a.c.}$ is increased further, the special test protector will begin to operate. $U_{a.c.}$ is reduced by a minimum amount until the special test protector does not operate and five surges should be applied.

I.1.3.5.2 Primary protector coordination test for equipment with PTCs

As $U_{a.c.}$ is increased further, the special test protector will begin to operate at the end of the test duration, see Figure I.1-14. Five surges should be applied with this generator voltage.

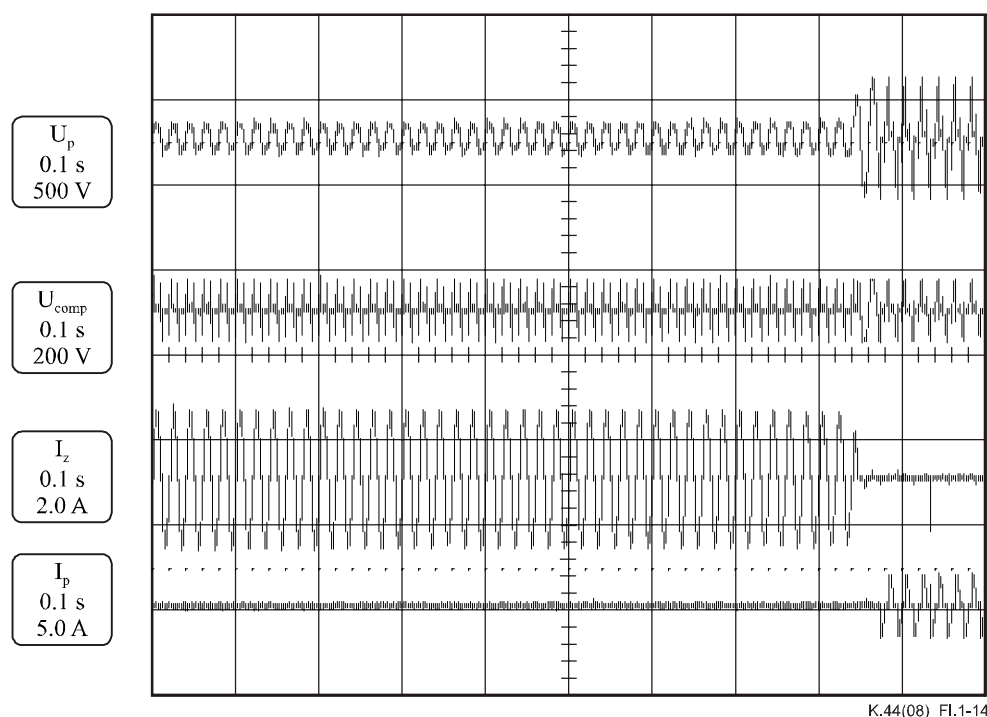


Figure I.1-14 – $U_{a.c.} = 280 V_{rms}$, special test protector operating

I.1.3.6 $U_{a.c.(max)}$ test

It is also necessary to apply five surges with the generator set to $U_{a.c.(max)}$, as this is the point of maximum current stress for the PTC.

In all cases where the PTC operates, it may be necessary to wait approximately 15 minutes between surges to allow the PTC to cool.

I.1.4 Mains power contact

Mains power contact surges can occur up to the amplitude of the mains voltage. The maximum voltage is nominally $240 V_{rms}$. The resistance between the source and the equipment is thought to be anywhere from 10Ω to 1000Ω .

Direct contact with electrical mains power can occur through network lines or cable faults, faulty or unapproved CPE, or other causes. The contact may not cause the operation of a power system circuit breaker. The a.c. currents resulting from direct contact may make effective protection both difficult and expensive. As such events are rare, equipment is not required to withstand overvoltages or overcurrents arising from direct contacts, but may fail in an acceptable manner.

The following particular dangers to equipment may arise:

- A contact near to the equipment where the combined resistance of the cable circuit and equipment termination is low and a high current flow occurs. This condition is simulated in the test in Figure I.1-15 by a resistance of 10Ω . The test current may be limited to lower values according to national regulations.
- A contact at the maximum distance from the equipment where the combined resistance of the cable circuit and equipment termination is high, and a small but harmful current flows continuously. This condition is simulated by a resistance of 1000Ω .
- Experience shows that, in reality, with values between 10 and 1000Ω , equipment is most susceptible to damage and fire hazard from current overheating.

Mains power contact generally has a source voltage equal to the local mains voltage. The resistance between the source and the linecard consists of the line resistance and the fault contact resistance. Experience has shown that the worst-case situation can occur over a narrow resistance range. To ensure that the worst-case condition is checked, the following test resistor values are used: 10 Ω, 20 Ω, 40 Ω, 80 Ω, 160 Ω, 300 Ω, 600 Ω and 1000 Ω.

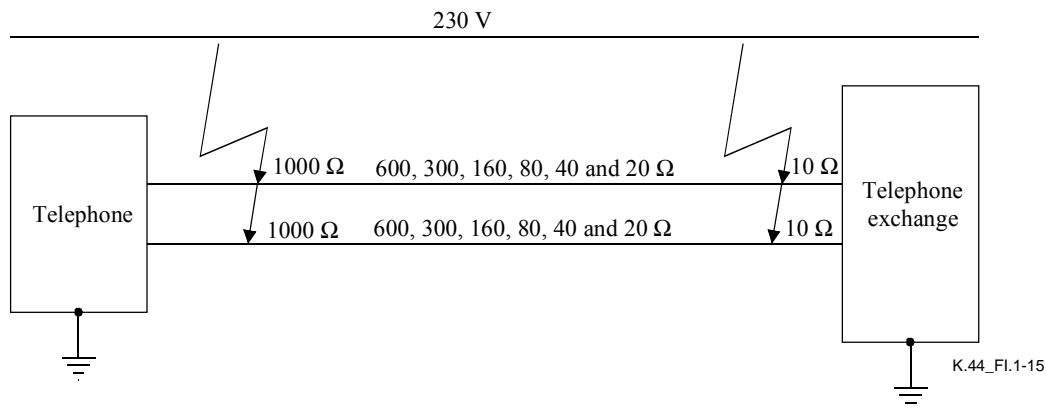


Figure I.1-15 – Mains power contact mechanism

It was agreed during the study period to perform the power contact with these eight resistor values as a result of a problem experienced by British Telecom. However, because the power contact test has a duration of 15 minutes, it was decided that testing with all eight resistors was too onerous and that the choice of intermediate resistors should be up to the person performing the test. There was also some discussion on reducing the test duration where it does not affect the test result. In this case, some guidance needs to be given on choosing the test resistor and test duration.

There are three known design methods for complying with the power contact test and these are: use of a solid state overcurrent protector (SSOP), use of a PTC, or use of a fusible link in series with the line current. For both the fuse link and the PTC, the worst case, from a circuit point of view, is the test resistor which results in maximum transfer of energy into the circuit. This can be determined by testing with all test resistor values and determining the maximum energy with an oscilloscope by measuring the voltage at the input of the circuit, and current flowing into the circuit, and then integrating the product of the voltage and current with time.

- a) A fusible link or resistor is designed to overheat and break open, interrupting excessive current flow into the equipment. Where minimal testing is to be performed, the test should be performed with the test resistor which causes the maximum energy dissipation in the circuit. Where it is proven that the resistor will not contract and reconnect the circuit when it has cooled, the test may be stopped once the current is interrupted.
- b) A PTC is designed to become "high resistance" when an excessive current flows through it. The worst-case current for a PTC is the lowest resistor, i.e., the highest peak current. Where minimal testing is to be performed, the test should be performed with the test resistor which causes the maximum energy dissipation in the circuit, and with the 10 Ω resistor.

Generally, once a PTC has operated, the current will be limited to low values and there will be no change for the remainder of the test. However, there have been cases where the PTC has started to break down at the end of the duration which can cause excessive heating and the possibility of a fire. Also, there have been cases where the PTC forms a relaxation oscillator with a long time constant. However, where it is proven that the PTC will not fail within the test time, or that there is no other factor which will alter the test result, the test may be stopped once the current has stabilized at a low value, which will prevent an overheating situation.

If the worst-case resistor cannot be determined, the test should be performed with all resistor values.

I.1.5 Rationale for test conditions

I.1.5.1 Port to port and port to earth testing

Correctly testing equipment is a complex task. There are many types of equipment construction practices, equipment locations, and earthing and bonding practices.

Equipment can generally be classified as earthed or floating (not earthed).

Equipment may be installed in a telecommunication centre where the resistance to ground is likely to be $<2 \Omega$, in the access or trunk network where the resistance to ground may be as high as 30Ω or in a customer premises where the resistance to ground may be as high as 300Ω .

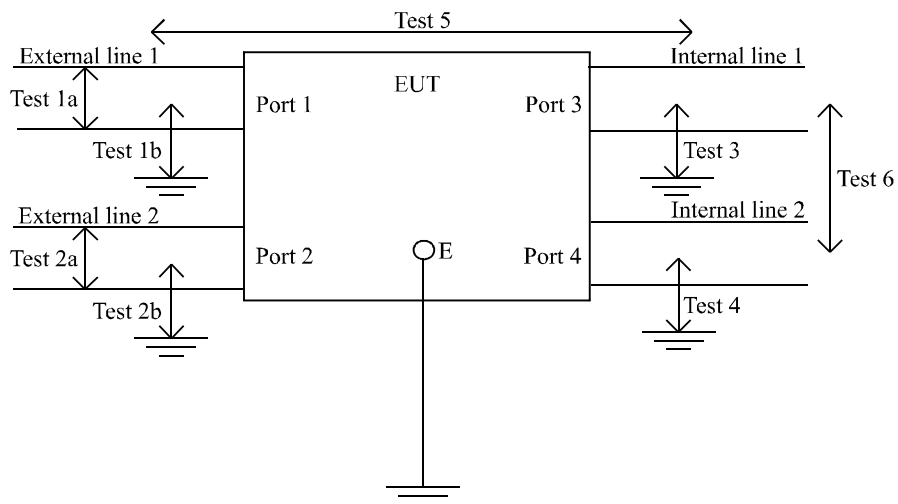
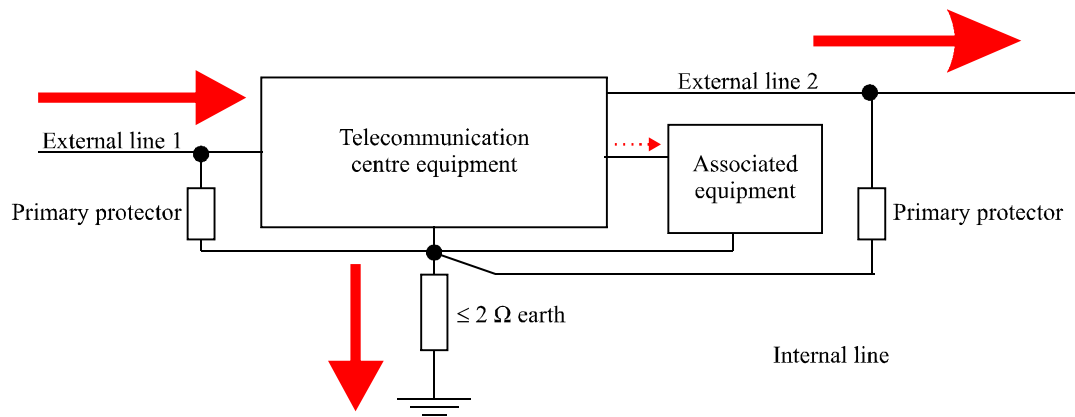
In some countries, an IT or TT power distribution system may be used. In these cases, the power network is not bonded to the customer premises earthing system. This is sometimes referred to as a separated earth system.

Whether or not the equipment is earthed, the resistance to ground of the installation affects the distribution of the incoming surge current. This distribution of surge current determines the required test method, see Figures I.1-16-I.1-18.

In Figure I.1-16, a telecommunication centre has a resistance to ground of $\leq 2 \Omega$; it can be seen that the majority of the surge current will be conducted external port to ground. Therefore, it is only necessary to perform line to line and port to ground tests on the external ports of the equipment. Note that the external port to internal port test of clause 7.2 is included in the external port to earth test. For internal ports, it is only necessary to test internal ports to earth. Note that the internal port to internal port test of clause 7.2 is included in the internal port to earth test.

In Figure I.1-17, it can be seen that, for earthed access network equipment, a significant current may be conducted from both port to ground and port to port. Therefore, it will be necessary to perform line to line, port to ground and port to port tests. For floating access network equipment, while substantial current is only conducted port to port on the external ports of the equipment, to check for capacitive current effects, it is still necessary to perform port to earth tests as well.

In Figure I.1-18, it can be seen that, for earthed customer equipment, a significant current may be conducted from both port to ground and port to port. Therefore, it will be necessary to perform line to line, port to ground and port to port tests. For floating customer equipment, while substantial current is only conducted port to port on the external ports of the equipment, to check for capacitive current effect, it is also necessary to perform port to earth tests.



K.44(08)_FI.1-16

Figure I.1-16 – Test conditions for telecommunication centre equipment

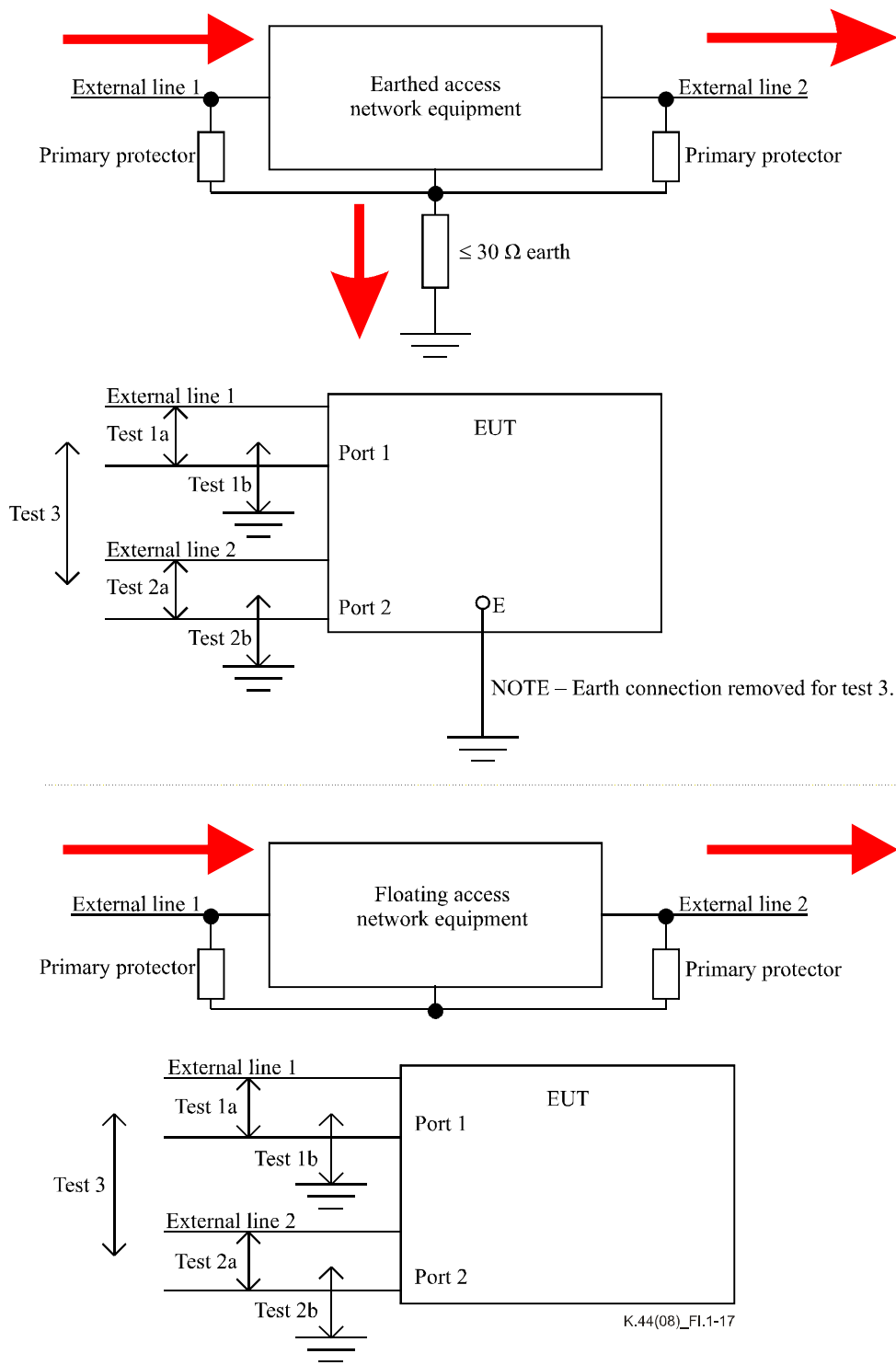
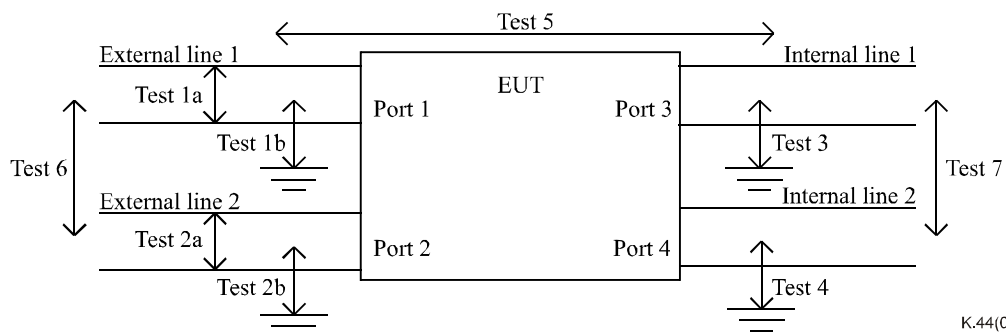
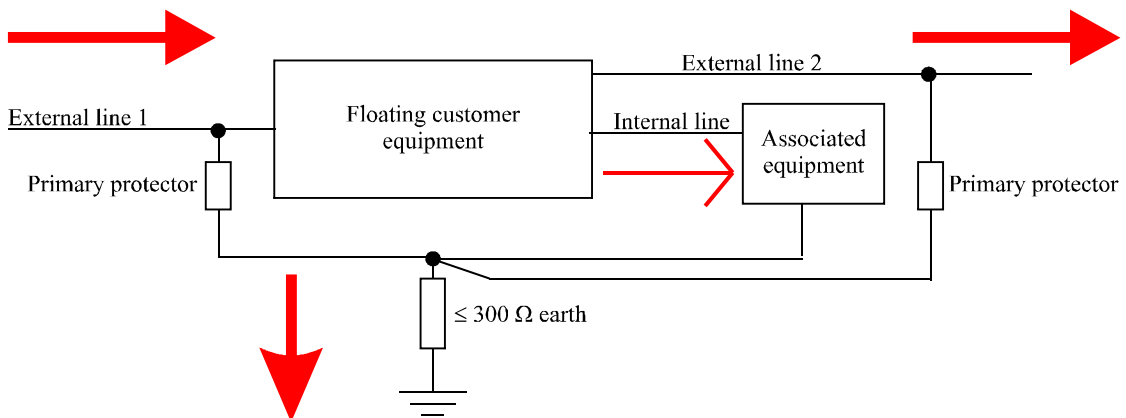
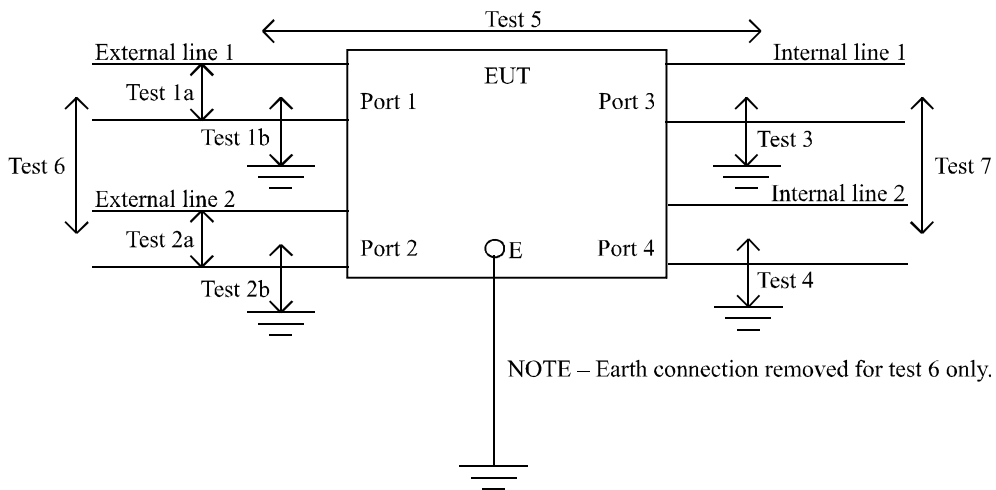
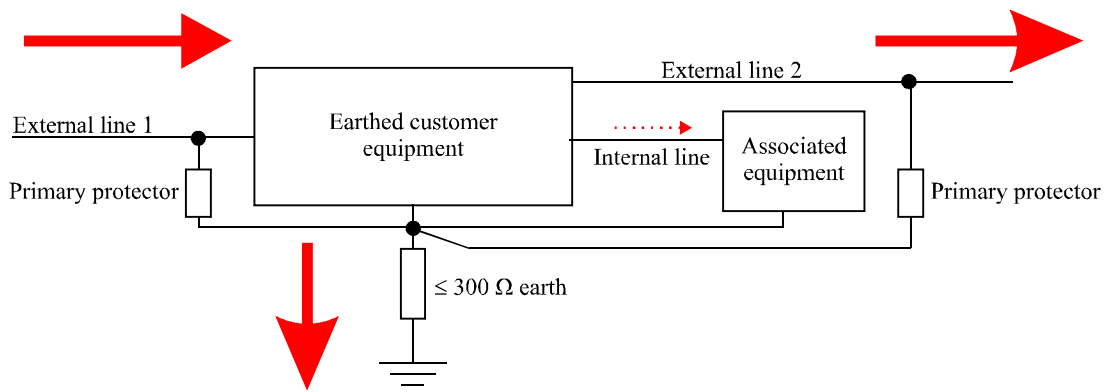


Figure I.1-17 – Scenario for outdoor equipment



K.44(08)_F1.1-18

Figure I.1-18 – Scenario for customer equipment

I.1.5.2 Terminations and SPDs on untested ports

Figure A.2-1 shows the possible ports of a complex piece of equipment.

This equipment has both external and internal ports, and the influence of these on the port being tested has to be considered. The EUT may be connected to auxiliary equipment within the same building via internal cables, or to equipment in another building via external cables. SPDs may be used on both types of ports, see Figure I.1-19.

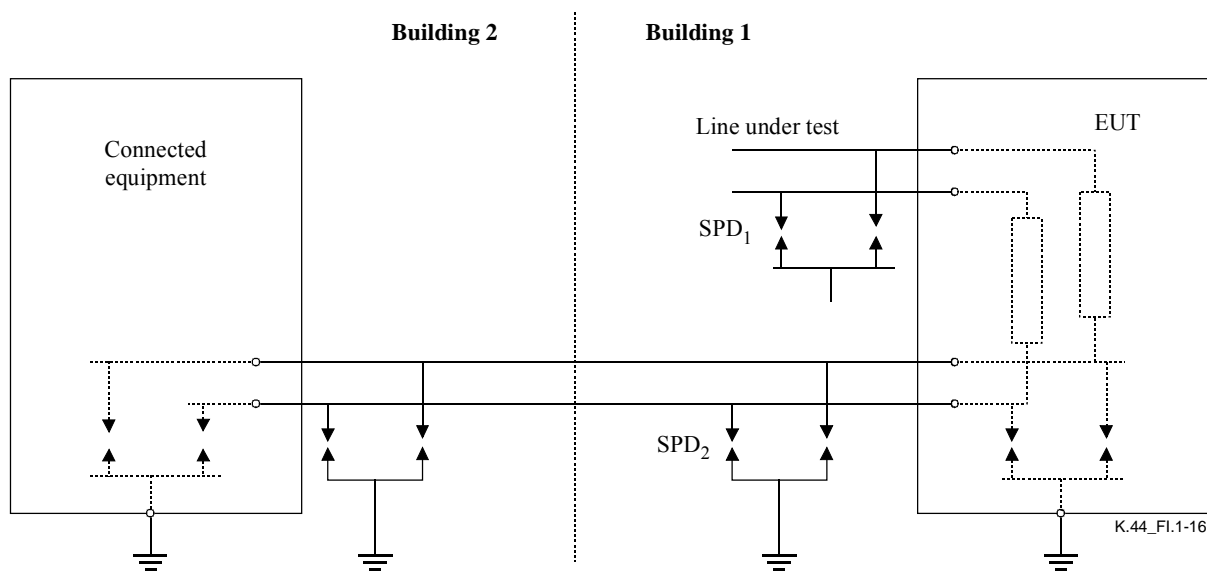


Figure I.1-19 – Terminations and SPDs on equipment

During testing, ports will need to be both terminated by connection to auxiliary equipment or by a terminating impedance or resistance, and connected to ground by a coupling element in turn. It is necessary to consider the differences between external ports and internal ports. Internal ports are considered to be connected to equipment that has the same reference point as the equipment being tested. External ports, on the other hand, can be connected to equipment with a different earth reference, e.g., in another building. This means that current may be conducted into one external port and out of another external port.

Issues to consider when terminating the equipment or grounding a port are:

- 1) When there is a possible low impedance path from the port being tested to an untested port, the possibility of the protector on the untested port operating first needs to be considered. This is done by using a special test protector on the tested port and a protector with the minimum allowed d.c. sparkover voltage on the untested port.
- 2) When there is more than one type of untested port, only one type of untested port should be terminated or have SPDs added at a time. The reason for this is that a low impedance path to one type of untested port may prevent current flow to another type of untested port.
- 3) Where one port may be connected internally to another port, e.g., under some operating conditions or power fail conditions, this port should be tested with the other port terminated and protected.
- 4) Where the equipment has high current carrying protection components, which eliminates the need for primary protection, it is necessary to remove the GDT on the port under test, and replace it by the test protector as described in clauses 8.2, 8.3 and 8.4. This is to ensure that coordination has been achieved. During testing of this port, the integral protector is to be left in position for untested ports. If this component is not removable, all tests are

performed with the protection provided and the manufacturer must provide a test report to show that the inherent and coordination tests were performed with the special test protector during the design tests.

- 5) Tests may need to be applied with the following three combinations of termination and coupling to ground of the untested ports, i.e.:
 - a) no termination and no coupling to ground;
 - b) no coupling to ground, add a termination;
 - c) both coupling to ground and a termination.

It is necessary in port to port testing to consider the following as the second port:

- 1) other lines/pairs of the port type being tested;
- 2) lines/pairs of other port types.

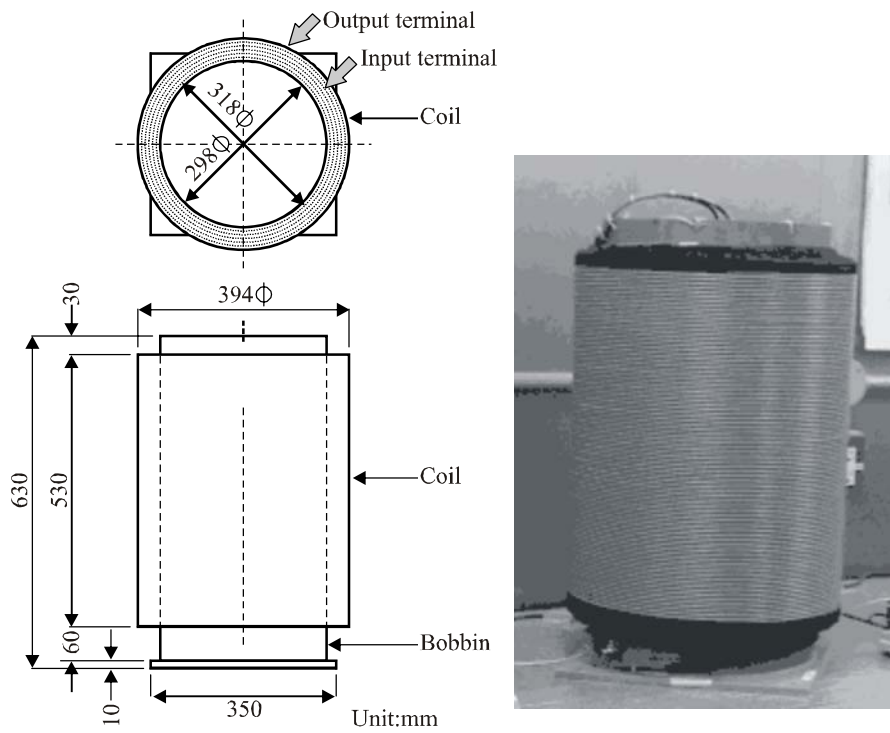
I.1.6 Decoupling networks

I.1.6.1 Decoupling inductance

The following is information on a 20 mH common mode inductor which could be used for decoupling symmetric pair ports as suggested by [IEC 61000-4-5]. Resistors can also be used to achieve decoupling, and are the preferred method.

The decoupling element affects the transmission in high-speed networks due to the resistance, the capacitance and the inductance of the decoupling element. This clause describes a common mode choke coil, whose value is 20 mH and described in [IEC 61000-4-5] for use as an inductor. However, the details of the inductor are not described in [IEC 61000-4-5] although the characteristics of the inductor are dependent on its configuration.

Figure I.1-20 shows the configuration and size of the described coil. The specifications of the element of the coil are summarized in Table I.1-1. In order to avoid the saturation of inductance and make the stray capacitance smaller, the coil is an air core type. The common mode impedance frequency characteristics are shown in Figure I.1-21. The impedance is greater than 1 k Ω from 10 kHz to 200 kHz. The normal mode impedance is shown in Figure I.1-22. The impedance is about 120 Ω . Frequency characteristics of the inductance and transmission loss are shown in Figures I.1-23 and I.1-24, respectively. The resonance occurs at about 46 kHz, but the transmission loss is smaller than 5 dB under 1 MHz.

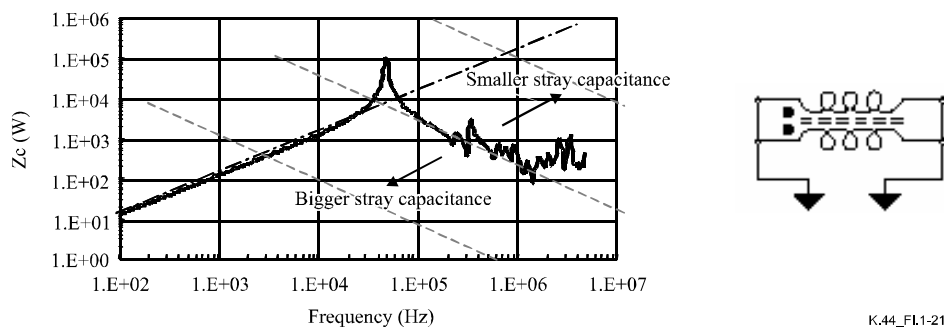


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Figure I.1-20 – Configuration, size and overview of 20 mH coil

Table I.1-1 – Specifications of coil

Items		Specifications
Wire	Material	Copper
	Sectional area	2 mm ²
How to turn		One pair of lines turned together
Turns		48 turns × 7 layers
Inductance		20 mH (common mode)



K.44_FI.1-21

Figure I.1-21 – Common mode impedance

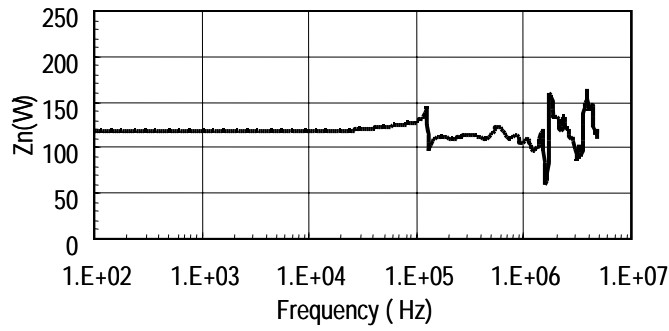


Figure I.1-22 – Normal mode impedance

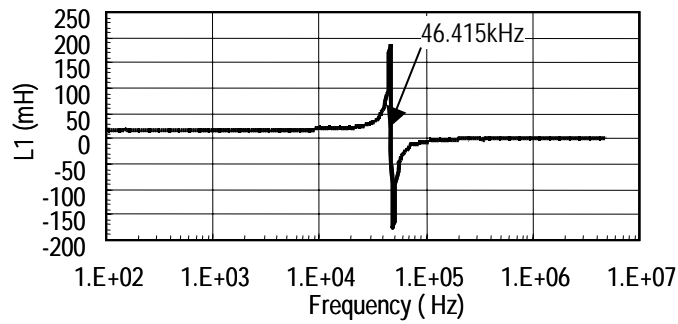
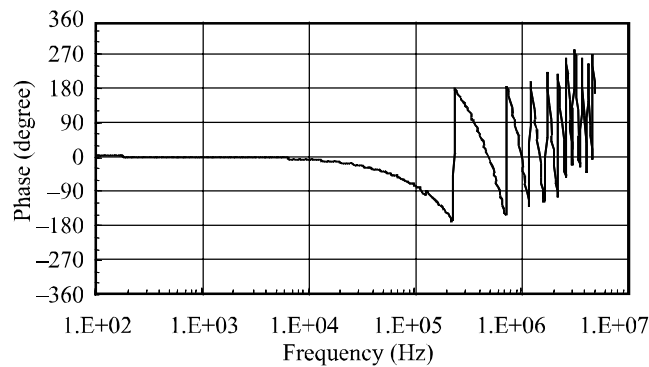
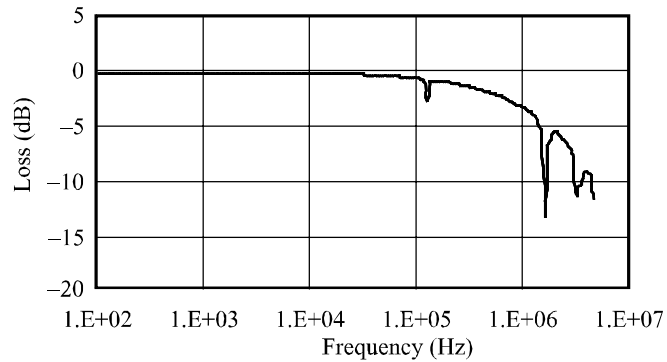


Figure I.1-23 – Frequency characteristics of inductance



K.44(08)_Fl.1-24

Figure I.1-24 – Frequency characteristics of transmission loss

I.1.6.2 Effect of inductance and resistance decoupling elements on digital circuits

Transmission characteristics were measured using an ISDN router and a VDSL modem. The test set-up for the ISDN is shown in Figure I.1-25. This set-up is for a longitudinal surge test, which is based on Figure A.5-1. The equipment that was used in this experiment is shown in Table I.1-2. Tested combinations of L_{dep} and R_{dep} , and the results are summarized in Table I.1-3. In all cases, the digital telephones and the PCs were connected.

The test setup for the VDSL is shown in Figures I.1-26 and I.1-27. The specifications of the VDSL modem which is tested are summarized in Table I.1-4. The results for the different decoupling methods are shown in Table I.1-5. It can be seen, for decoupling methods 4 and 5, that the throughput decreases slightly. In row 6 no decoupling element was used, only a 2 m length of Cat-5 cable, to show the throughput for a normal situation.

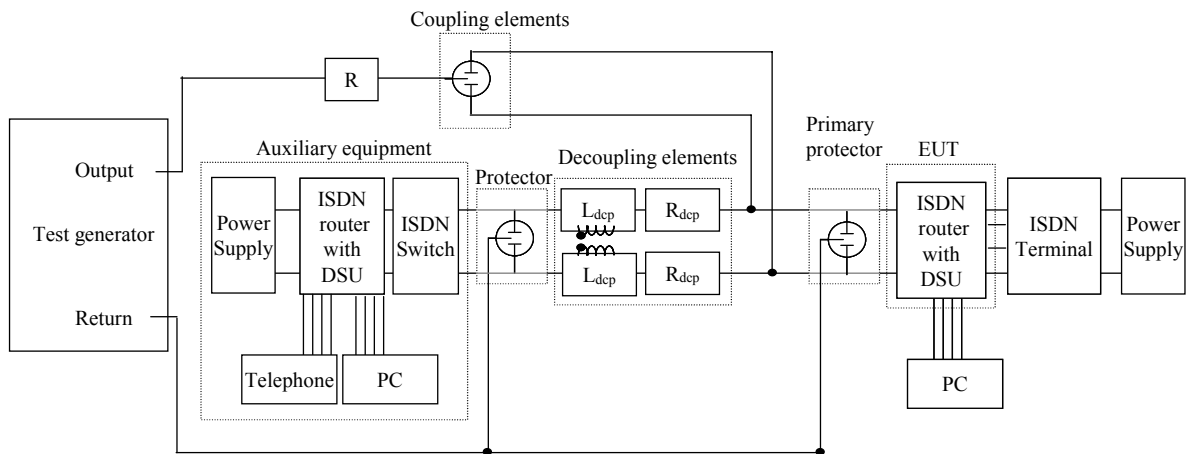


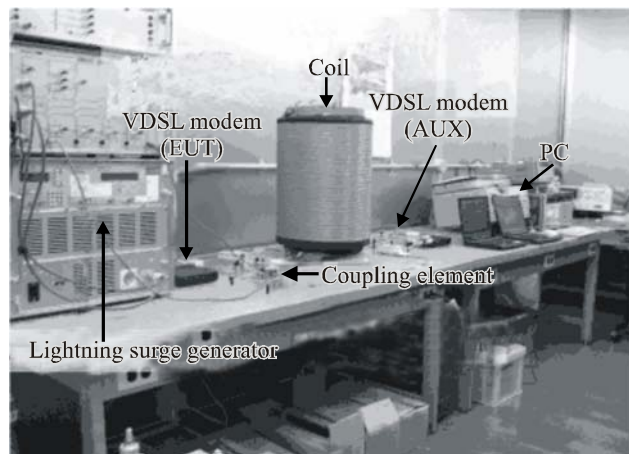
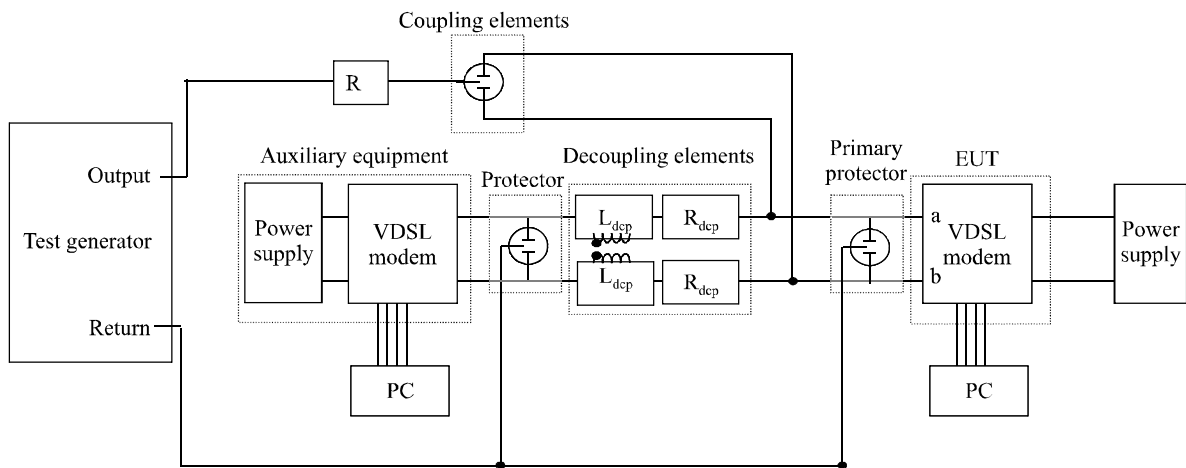
Figure I.1-25 – Test set-up for ISDN equipment

Table I.1-2 – ISDN equipment

Item	Equipment
Digital telephone (EUT side)	S-1000 (NTT)
Digital telephone (AUX side)	DC-R2100 (NTT)
ISDN router (EUT)	MN128-SOHO (NTT-ME)
ISDN router (AUX side)	MN128-SOHO (NTT-ME)
ISDN switch	I64-4LINES and iNet-U2-LINES
Test generator	PSURGE 4.1 (HAEFELY)

Table I.1-3 – Decoupling element and results

Test case	L_{dep} (mH)	R_{dep} (Ω)	Result
1	–	50	Good
2	–	100	Good
3	–	200	Good
4	20	–	Good
5	20	200	Good



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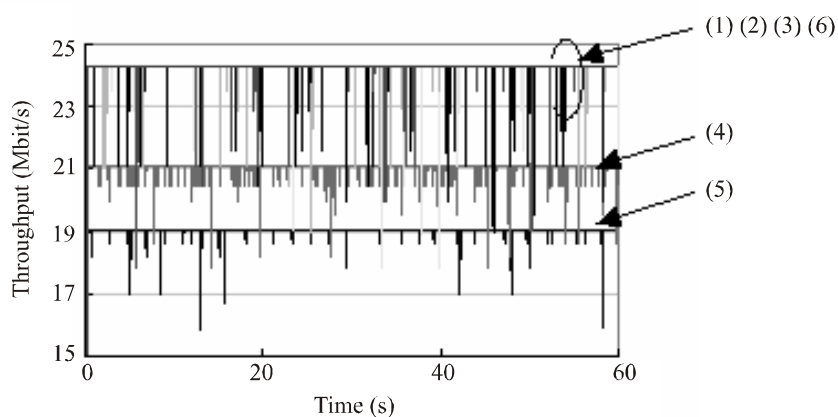
Figure I.1-26 – Test set up for VDSL equipment

Table I.1-4 – Specifications of VDSL modem

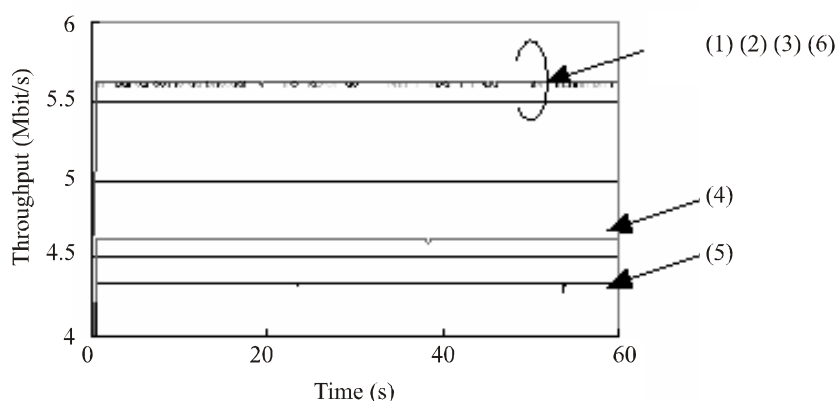
Item	VDSL
Modulation	DMT
Communication	Full duplex (TDD)
Data rate	28.8 Mbit/s 51.2 Mbit/s/6.4 Mbit/s
Band allocation	1.5 Mbit/s or less, 64 kbit/s units 1.5 Mbit/s or more, 1 Mbit/s units
Transmission distance	300 m (28.8 Mbit/s) 300 m (51.2 Mbit/s/6.4 Mbit/s) 1 km (13 Mbit/s)
Error correction	Error correction for impulse noise, etc.
Splitters	Required

Table I.1-5 – Decoupling element and results

Test case	L_{dcp} (mH)	R_{dcp} (Ω)	Average throughput (Mbit/s)	
			Master side	Slave side
1	–	50	24	5.6
2	–	100	24	5.6
3	–	200	24	5.6
4	20	–	21	4.6
5	20	200	19	4.3
6	–	–	24	5.6



a) Master side



b) Slave side

K.44(08)_FI.1-27

Figure I.1-27 – Measurement results of throughput

I.1.7 Mains port testing

Confusion sometimes occurs over what tests are required, i.e., A to N and A/N to E, for various systems. In a mains distribution system with the neutral earthed at the customer premises it may be thought not necessary to perform A/N to earth tests. In systems where the neutral is not earthed, it may be thought that the A to N test should be performed with the generator floating. Both these cases are illustrated in Figure I.1-28 below. In both cases, an A to N surge results in both a transverse and longitudinal surge in respect of the EUT and its secondary circuits. In the interests of

repeatability and to have the same test for different power systems, it is better to perform the transverse test without a longitudinal surge and the longitudinal test without a transverse surge. This is achieved using the test circuits given in Figures A.6.4-1 (for transverse surges), A.6.4-2 (for port to earth surges) and A.6.4-3 (for port to port surges)

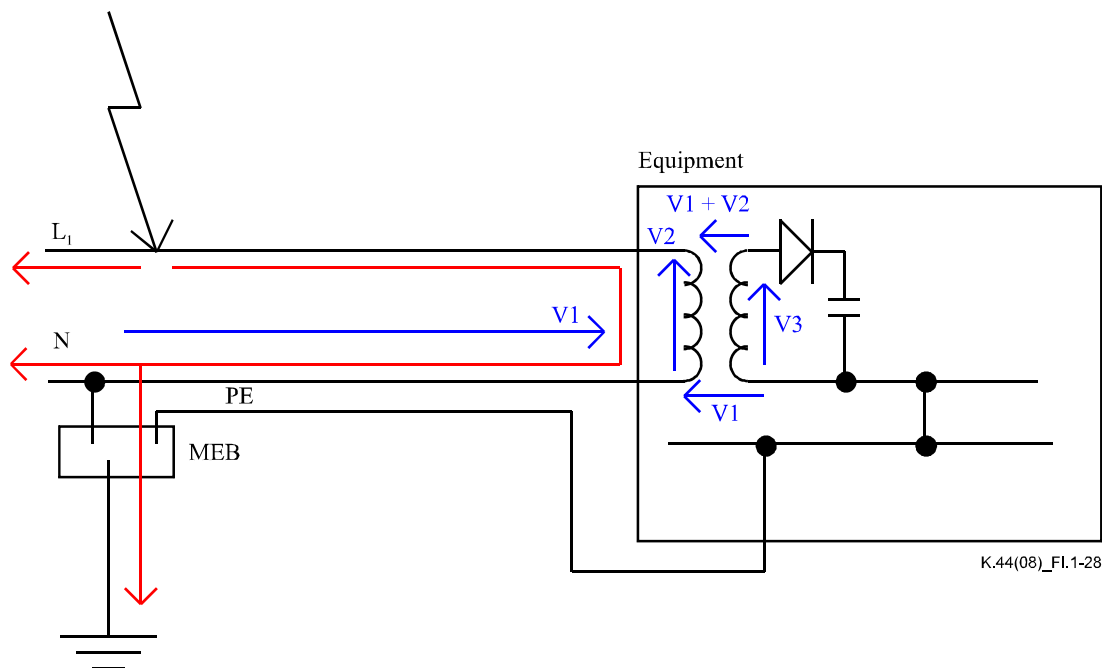
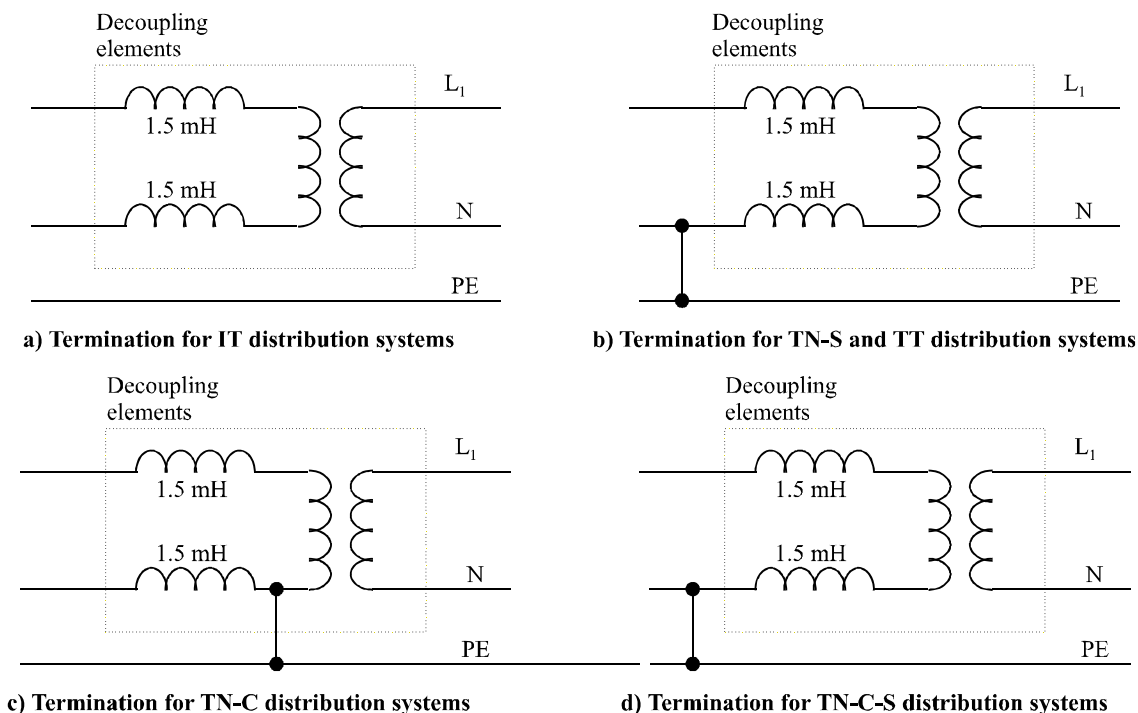
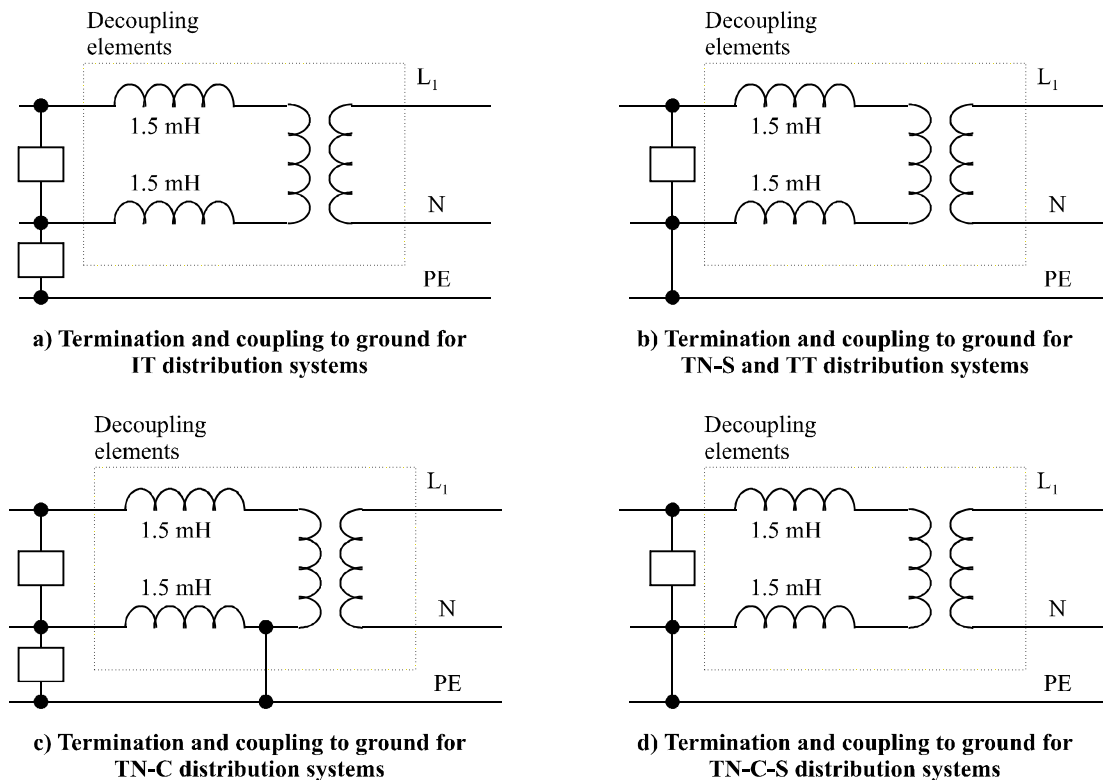


Figure I.1-28 – Effect of an A to N surge on equipment



K.44(08)_Fl.1-29

Figure I.1-29 – Terminations for mains ports



K.44(08)_FI.1-30

Figure I.1-30 – Terminations and coupling to ground for mains ports

In the interests of global testing, it is recommended that Figure I.1-29a be used as a termination for an untested mains port, and that Figure I.1-30b be used to couple an untested mains port to ground.

I.2 Range of lightning and power induction test levels

I.2.1 Lightning

I.2.1.1 Inherent test levels

The range of test voltages used in product Recommendations for the inherent resistibility test levels could be from 1.0 kV to 5.0 kV. Traditionally, a test voltage of 1.0 kV has been used in large telecommunication buildings. This is because the majority of surges will be less than 1.0 kV and it is relatively easy to install reliable primary protection on the MDF when required. A figure as high as 5.0 kV could be considered for CPE as it is in a far less controlled environment and it is far more difficult to install GDTs.

I.2.1.2 Coordination test levels

The maximum test level for the coordination requirement has traditionally been 4.0 kV. However, recent measurements have shown that surge levels in excess of 7.0 kV do occur. An optional test level of up to 10.0 kV is allowed. The higher test level has a higher dU/dt. This results in a higher firing voltage of the primary protector and higher capacitive charging currents in the equipment.

I.2.2 Power induction test levels

I.2.2.1 Inherent test levels

Traditionally, the inherent test has been $0.2 \text{ A}^2\text{s}$ for equipment in telecommunication centres and CPE. With the liberalization of customer premises, the use of primary protection is less certain and the inherent test level may need to be higher for CPE, e.g., $1.0 \text{ A}^2\text{s}$.

I.2.2.2 Inherent/coordination test levels

Traditionally, the test level for the test with primary protection was $1.0 \text{ A}^2\text{s}$. An enhanced test level of $10 \text{ A}^2\text{s}$ has been introduced to take into account that some countries have higher levels of power induction, maximum level of power induction into short lines ($200 \ \Omega$) or the need for a high grade of service due to changing regulatory requirements.

The method of specifying the requirements for equipment may need to be different. [ITU-T K.20] specifies a $U_{c(\max)}$ of 600 V through $600 \ \Omega$ for 1 second. Measurements have shown that the range of time for which the fault current flows is from 0 to 3.2 seconds and that the current flowing in a telecommunication circuit can vary from 0 to 9 A_{rms} , see Figure I.1-8. Tests on a resistor have shown that its I^2t rating decreases with increasing current for a constant I^2t . This shows that the inherent/coordination test has to be performed at the maximum current which occurs.

I.3 Relationship between this Recommendation and other product or product family Recommendations

[ITU-T K.20] is for the equipment that is installed in a telecommunication centre. There is a proper grounding system and metal structure described in [ITU-T K.27], so the environment is not so exposed. However, due to the large number of telecommunication cables, the total current which flows into the building will be large.

[ITU-T K.21] is for the equipment that is installed in a customer premises. It assumes that good earthing and bonding practices according to [ITU-T K.66] have been followed. If bonding between the telecommunications and power services has not been implemented, damage to telecommunication equipment may occur. If damage does occur, solutions according to clauses 5 and II.6 should be implemented.

[ITU-T K.45] is for the equipment that is installed between the telecommunication centre and the customer premises. The grounding system is not as good as a telecommunication centre, but the system is under the control of an operator. There is some merit in that the small structure allows ideal equipotential bonding.

Figure I.3-1 shows an example of the location of the equipment and Recommendations to be applied. If the equipment is used in more than one location, it has to be tested according to all relevant Recommendations.

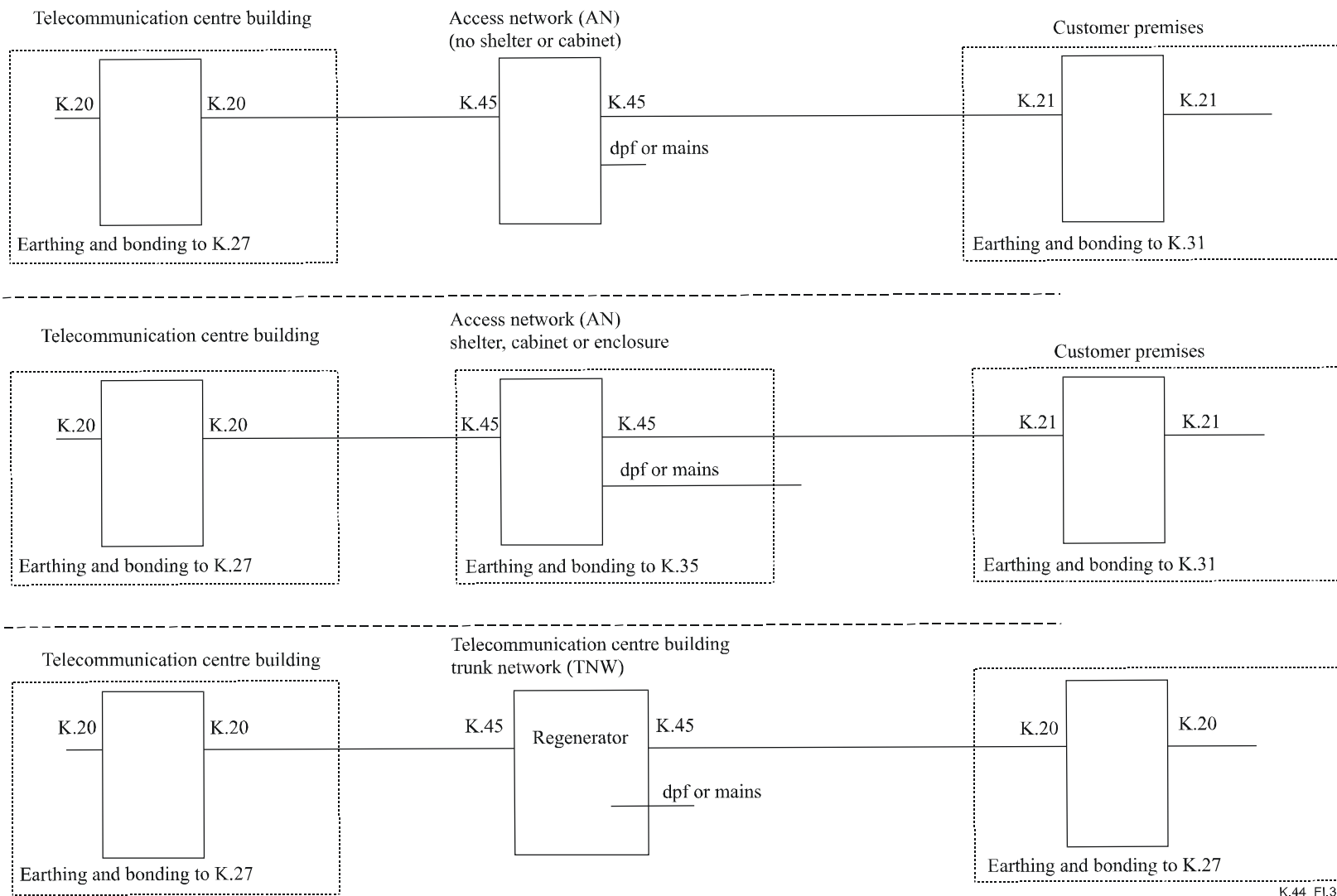


Figure I.3-1 – Example configuration of a telecommunication network showing the border between a telecommunication centre, the access/trunk network and customer premises

Appendix II

Supplementary information for manufacturers and operators

(This appendix does not form an integral part of this Recommendation)

II.1 Introduction

The following information is under study by ITU-T. It has been provided in this appendix for the information of manufacturers and operators and to promote discussion on these topics.

II.2 Primary protection coordination

The effects of the operation of primary protection are described in [ITU-T K.11].

To ensure the coordination of the protection components with the equipment, it is necessary to check that:

- 1) the equipment will not be damaged by worst-case voltages that may appear between the input terminals and between an input terminal and the equipment ground reference;
- 2) the equipment will not be damaged or interfered with by the operation of the primary protection over the complete range of surge voltages.

The operation of primary protection with a switching characteristic has two effects:

- It limits the maximum voltage applied to the equipment and hence, depending on the internal impedance of the equipment, the maximum current which the equipment must withstand.
- It produces a very rapid change of voltage and current, which by inductive or capacitive effects can reach sensitive parts of the equipment not apparently exposed to line voltages.

II.2.1 Primary protection does not operate

For surge voltages where the primary protection is not activated, attention should be paid to the value of the currents that can flow in the internal cabling network. Large currents in the internal cabling network may disturb other equipment. [ITU-T K.27] describes earthing and bonding inside a telecommunication building and [ITU-T K.11] treats coordination with electrical protection devices.

II.2.2 Primary protection does operate

Lightning surge simulation requires special attention to be paid to:

- a change in the operating voltage of GDTs with voltage rate of rise;
- potential differences developed across the protection frame and any associated earth wiring due to high current flow;
- the fast dU/dt , caused by the operation of the GDT, which may damage sensitive components or cause misoperation (equipment lockup or corruption of data in memories).

To check coordination with primary protection, attention must be paid to the operating principles of the GDT. Firstly, the 10/700 μs firing voltage of GDT, see Figure I.1-4, is generally higher than the d.c. firing voltage but generally less than the 1 kV/ μs firing voltage. Secondly, the d.c. firing voltage, and hence the 10/700 μs firing voltage, can vary considerably for the same protector type. For example, the d.c. firing voltage of a 230 V GDT is allowed to vary from 180 V to 300 V [ITU-T K.12].

For these reasons, primary protection coordination is checked by replacing the agreed primary protector with a special test protector. The d.c. firing voltage of the special test protector is to be equal to 1.15 times the specified maximum d.c. firing voltage of the agreed primary protector. The tolerance on the firing voltage is $\pm 5\%$. For a 230 V primary protector, the firing voltage of the special test protector is 345 V ± 17 V. This test protector is used for both the lightning, power induction and power contact tests. The special test protector should have a similar characteristic to the agreed primary protector.

II.2.3 Principles of coordination

It is written in [ITU-T K.11] that:

- No device exists which has the characteristics for ideally suppressing all voltages and currents connected with disturbances.
- It is sometimes necessary to use more than one protective device.

Generally, high-current devices operate slowly and there remains a residual voltage. Fast-operating semiconductor devices operate fast enough but can only handle less energy than high-current devices. Therefore, it is necessary to have a ladder circuit to reduce the surge energy step by step to the level which is harmless to the equipment. This type of protection is called multistage protection.

Figure II.2-1a shows the principle of protection by a ladder circuit.

A primary protector is applied at the location of the border, such as an MDF external to the EUT. The most stressful energy is bypassed to ground at this point. An inherent protector is inside the EUT, and it diverts the residual energy of the primary protector. There may also be a third protector inside the EUT that is part of the black-box.

It is important that there should be resistance between the protectors so as not to connect to each other directly and then the circuit looks like a ladder. Considering the coordination between primary and inherent protection, there should be resistance R_{in} . This R_{in} is virtually the same as the input resistance of the EUT when the inherent protector, such as a PNP device or a diode, turns on and connects R_{in} to ground. Figure II.2-1b shows the equivalent circuit when the inherent protector turns on. If there is no resistance between the primary and inherent protector, only the protector which has the lower turn-on voltage will operate. In this case, only the inherent protector operates and it prevents the operation of the primary protector, so coordination is not achieved. R_{in} is necessary to increase the voltage across the primary protector high enough to cause the primary protector to operate.

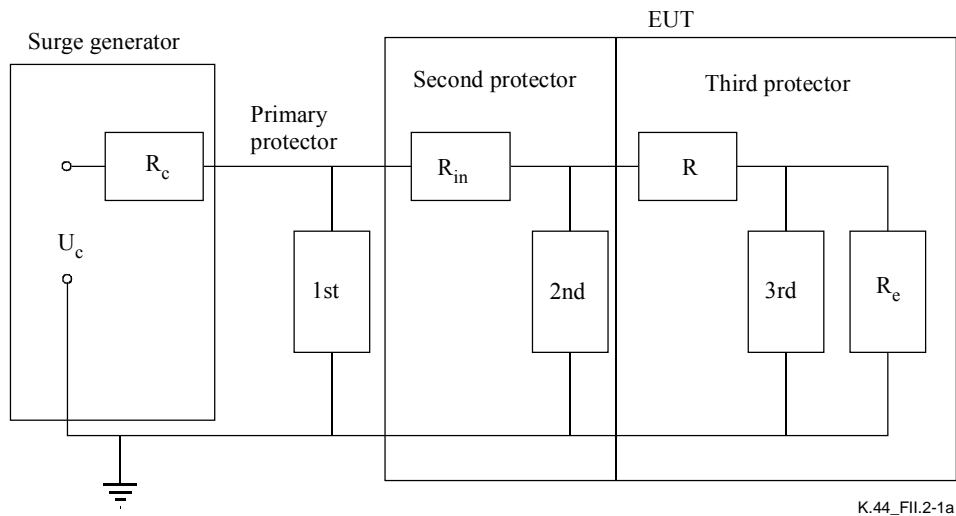
The point is that the inherent protector usually turns on at a lower voltage than the primary protector at the MDF. At first, the current flows into the black-box and generates voltage across the inherent protector and it turns on. Then the current that flows through R_{in} and the inherent protector generates the voltage across the primary protector.

Therefore, the inherent protector is not a subsidiary but an essential device because it usually operates earlier than the primary protector and protects the following components. The voltage drop across the coordination resistance, due to the current flowing in the inherent protector, operates the primary protector which bypasses the majority of the surge energy to ground.

In a traditional circuit using a bulky transformer or coil inside the EUT, it is possible that there is no inherent protector. The sum of the resistance, R_{in} plus R_e , is high enough that the primary protector turns on without much current flowing into the EUT. Figure II.2-1c shows such an equivalent circuit.

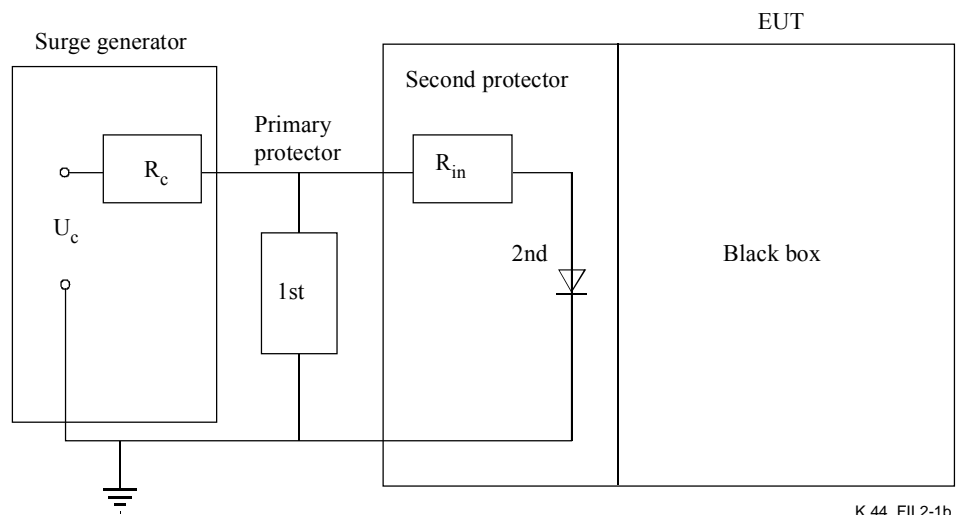
If there is an inherent protector, such as semiconductor SPD in the EUT, it usually operates faster than the primary protector at the MDF. If there is no resistance between the primary and the inherent protector, the operation of the inherent protector disturbs the operation of the primary protector. Coordination is achieved when there is sufficient resistance between the protectors, and

the voltage drop across the resistance allows the primary protection to operate correctly. When coordination is designed correctly, the EUT is not damaged up to the maximum test level. Above the maximum test level, the primary protector must operate for lightning surges.



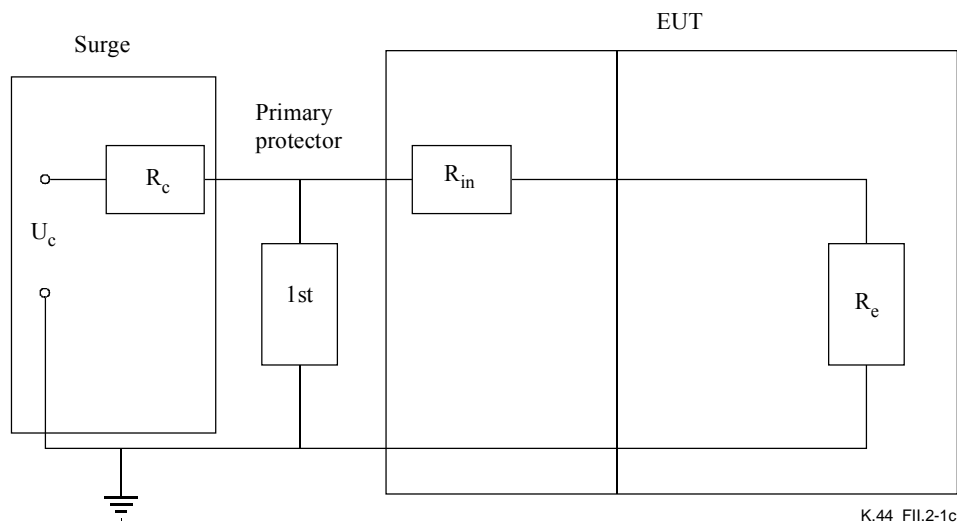
K.44_FII.2-1a

Figure II.2-1a – Principle of protection by ladder circuits



K.44_FII.2-1b

Figure II.2-1b – Equivalent circuit when the second protector turns on



K.44_FII.2-1c

Figure II.2-1c – Robust circuits with no second protector

II.2.4 Coordination testing of switching and clamping SPDs

IEC TS 62305-4 contains information on the theory of coordination. The following text contains the specific tests that need to be performed to confirm coordination.

There are four combinations of SPDs and these are shown in Figure II.2-2.

Figure II.2-2a: To perform coordination testing of the SPDs in Figure II.2-2a, it is necessary to perform the following tests:

- 1) U_c set to produce a waveshape just under the firing voltage of the primary protection (maximum energy into inherent protector);
- 2) U_c set to $U_{c(max)}$ (worst case dV/dt and highest peak current into inherent protection).

Figure II.2-2b: To perform coordination testing of the SPDs in Figure II.2-2b, it is necessary to perform the following tests:

- 1) U_c set to produce a waveshape just under the firing voltage of the inherent protection (maximum energy into electronics);
- 2) U_c set to produce a waveshape just under the firing voltage of the primary protection (maximum energy into inherent protector);
- 3) U_c set to $U_{c(max)}$ (worst case dV/dt and highest peak current into inherent protection).

Figure II.2-2c: To perform coordination testing of the SPDs in Figure II.2-2c it is necessary to perform the following test:

- 1) U_c set to $U_{c(max)}$ (worst case dV/dt and highest peak current into inherent protection).

Figure II.2-2d: To perform coordination testing of the SPDs in Figure II.2-2d, it is necessary to perform the following test:

- 1) U_c set to produce a waveshape just under the firing voltage of the inherent protection (maximum energy into electronics);
- 2) U_c set to $U_{c(max)}$ (worst case dV/dt and highest peak current into inherent protection).

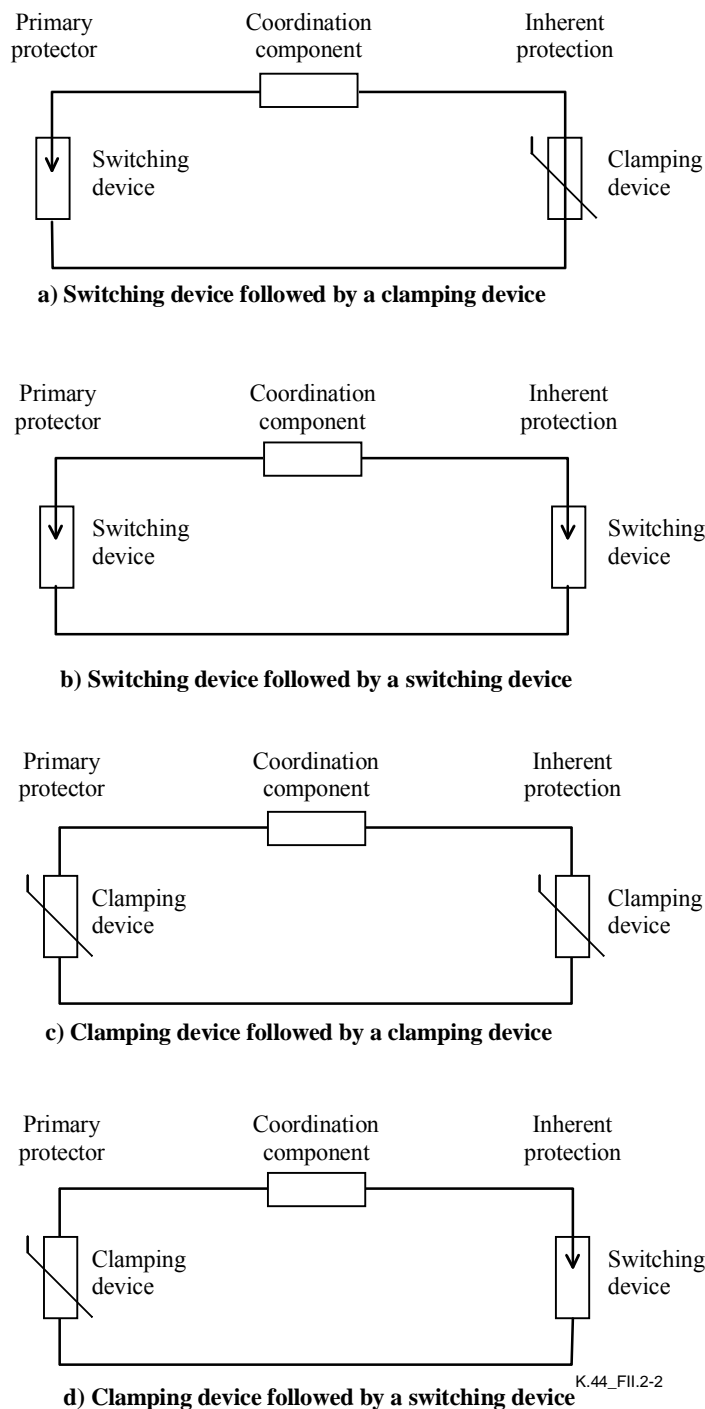


Figure II.2-2 – Combinations of SPDs

II.3 MDF voltage at the input of equipment

II.3.1 General

The firing voltage of a GDT depends on dU/dt . If R_p is known, the dU/dt of U_{si} can be calculated by Spice transient simulation. Using the firing voltage versus dU/dt information in the GDT data sheet, the actual firing voltage for each condition can be simulated. Figure II.3-3 shows the simulation results for a 1 m MDF cable between the GDT and the equipment and a 1 m MDF earth cable. It shows that the GDT operates at a higher voltage in a shorter period of time when U_c is high. If U_c is small, the GDT operates at a lower voltage in a longer period of time.

Figure II.3-4 shows the same simulation but with a 10 m MDF cable between the GDT and the equipment and a 10 m MDF earth cable. The inductance of the 10 m MDF cable and the 10 m earth cable is almost 10 μH , respectively. The total inductance of 20 μH can be an effective low pass filter for the high speed residual voltage caused by GDT operation. The MDF cable suppresses the high dU/dt surge caused by operation of the GDT. This simulation shows that the test lead between the surge generator and the EUT has to be short, e.g., less than 2 m.

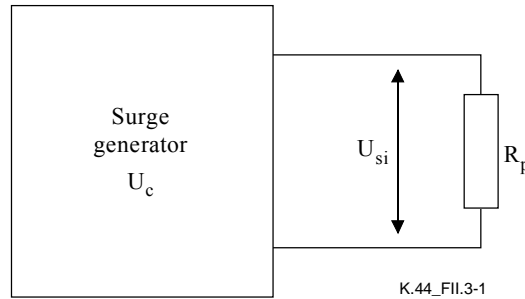


Figure II.3-1 – A model to calculate the dU/dt of U_{si}

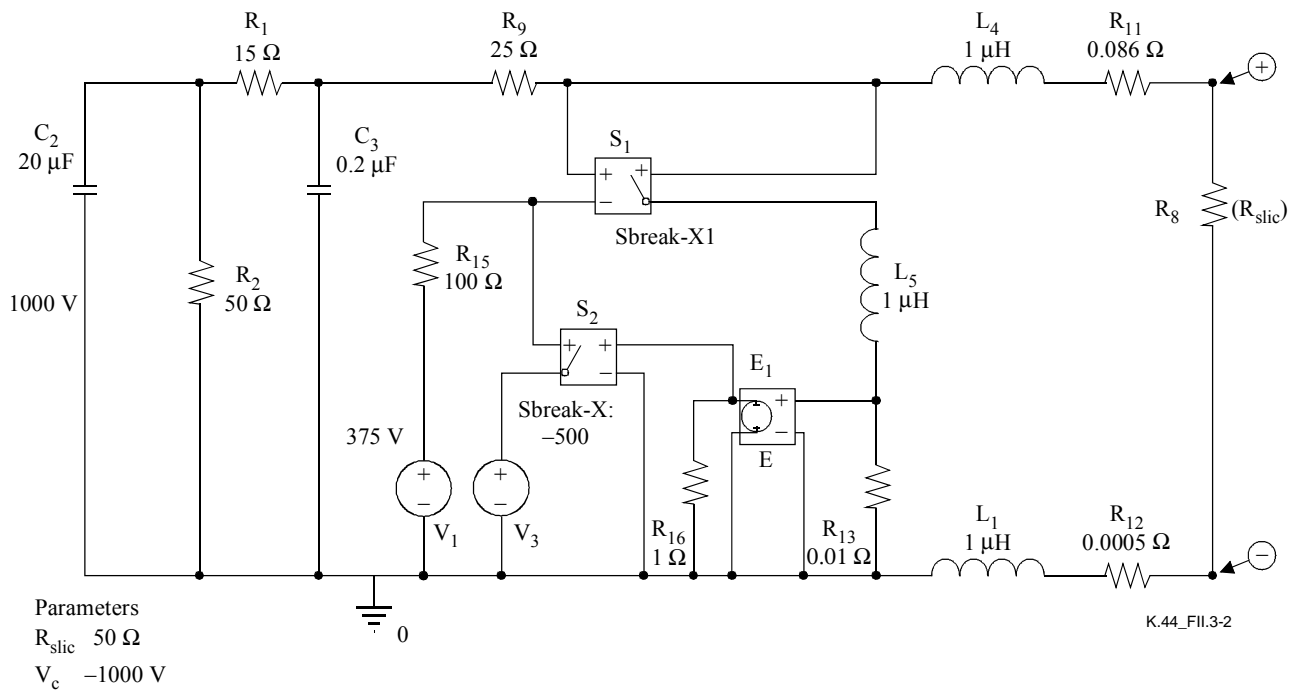


Figure II.3-2 – The Spice model used to calculate the reduced voltage at the equipment input due to the impedance of the MDF cable

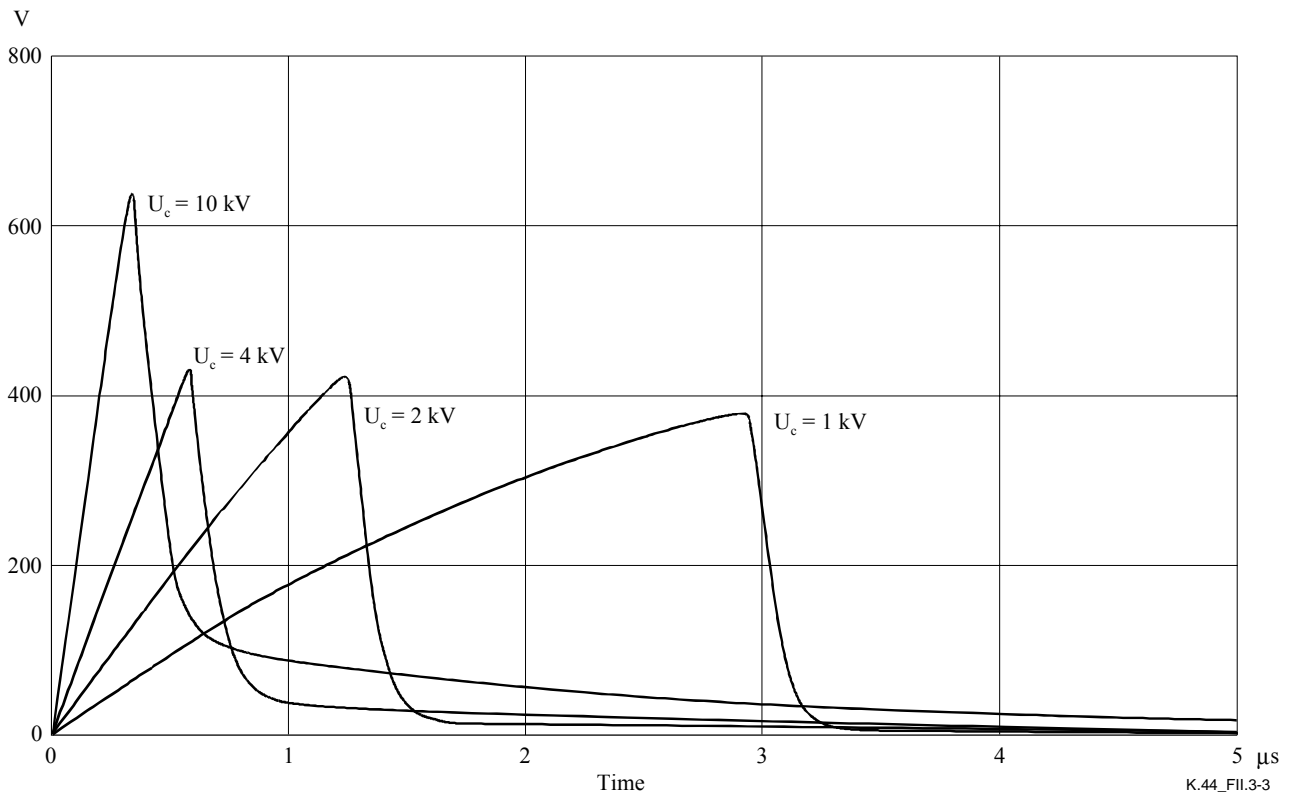


Figure II.3-3 – MDF cable is 1 m

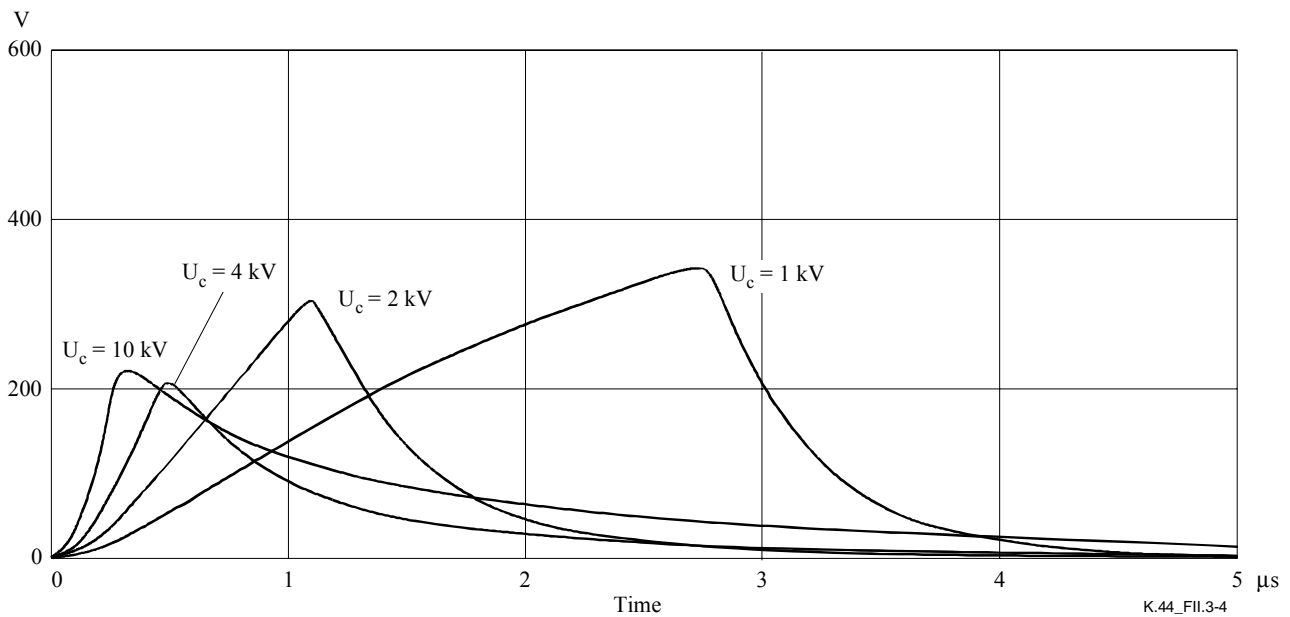


Figure II.3-4 – MDF cable is 10 m

II.3.2 MDF earth wire voltage drop

The inductance of the MDF cable between the primary protector and the EUT has a good effect for high dU/dt surges, but the inductance of the MDF earth cable has the opposite effect. This is particularly so when it is considered that the current from all GDTs, which have operated, flows in the MDF earth cable. Inductance is a function of the length of the cable and does not change much if the diameter of the cable is changed. The length of MDF earth cable cannot be zero, so there is always inductance. The voltage drop caused by the MDF earth cable is due to the surge current

which flows after the GDT operates. The voltage drop of the MDF earth cable appears at the input of the equipment, so it is necessary to have a bonding configuration which will have the minimum possible inductance and resistance. Figure II.3-5 shows where inductance of the MDF earth cable exists.

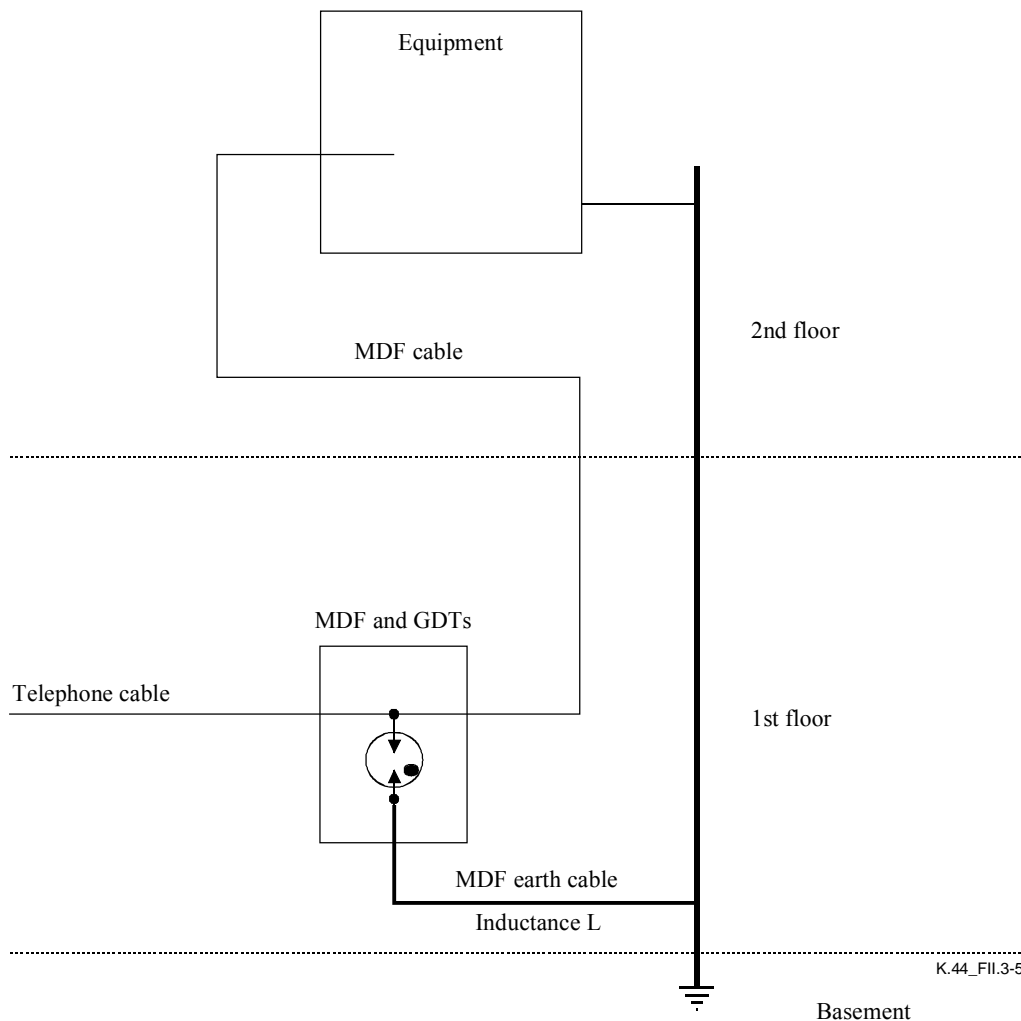


Figure II.3-5 – Inductance of MDF earth cable

When there is significant length of MDF earth cable, as shown in Figure II.3-5, a multiple cable or mesh configuration is desirable.

Multiple cables which are not tied together but separately connected will reduce the inductance nearly $1/N$ where N is the number of cables (see Figure II.3-6).

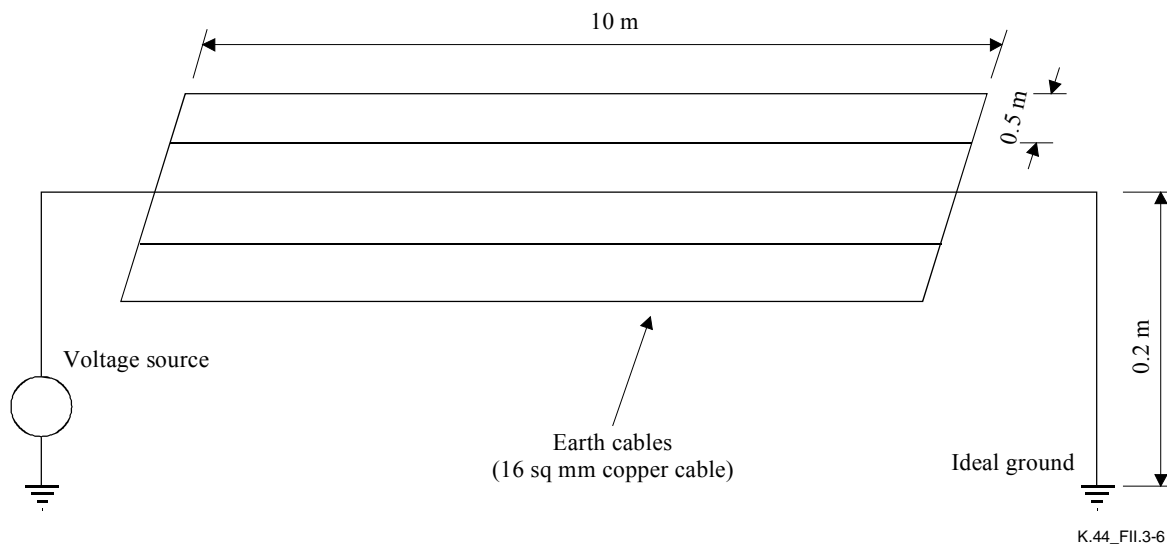


Figure II.3-6 – Use of multiple earth wires to reduce inductance

The inductance calculated using ACCUFIELD simulation is shown in Table II.3-1.

Table II.3-1 – Inductance versus number of conductors

N (number of conductors)	Total inductance
1	10.89 μH
2	6.16 μH
3	4.39 μH
5	3.05 μH

II.3.3 Earth voltage drop test

Where there is an external protection frame and/or an earth wire connecting it to the earth bar, high currents flowing in the protection frame or the earth wire will cause a voltage drop at the input of the equipment, see Figure II.3-7.

Damage due to an earth voltage drop has been observed in the United Kingdom and Australia.

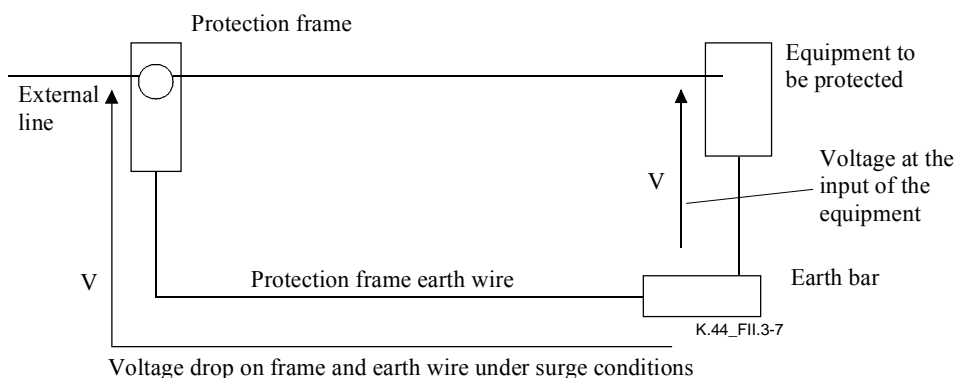


Figure II.3-7 – Voltage drop in earth wires

II.3.3.1 United Kingdom's example of earth voltage drop problem

Some small switching systems installed at customer premises have suffered damage due to the potential difference created by the earth bonding wires of the protection and switching equipment. The bonding for the protection was typically routed over an indirect route to the main earth terminal. The equipment protective earth was connected to the power system wiring earth, and hence the main earth terminal. Due to differences in impedance, a large potential difference was developed between the equipment line terminals and the protective earth of the equipment. This resulted in a small flash-over from the circuitry to the equipment chassis, damaging the equipment. The solution was to bond the protection as close to the equipment as possible using the correct d.c. sparkover voltage protectors, such that mains could not get on the line in the event of a power fault on the equipment earth. A further problem has been experienced where the equipment was very well earthed, with what appeared to be short bonds to the common earth point, i.e., no different to many thousands of other installations, and a very low d.c. earth resistance from the MDF to the MET. Lightning was causing damage to the equipment even though protectors had been fitted. Deeper investigation showed that the bond from the MDF blocks to the earth riser was a short 'pig-tail' of earth wire, creating a high impedance to surge energy, and hence high volt drop in the earth. When the earth connection is corrected, the problem is solved. Anything greater than about a 20- Ω impedance can cause this problem, so even a small inductance can cause a problem.

II.3.3.2 Australian example of an earth voltage drop problem at customer premises

Australia has suffered a lot of lightning damage to small customer switching systems as a result of potential differences occurring in the telecommunication line and the mains power supply due to the length of the bond wire between the protection frame and the main earth terminal. Where it was not possible to reduce the bond wire length to less than a few metres, a combined telecommunication and mains port protection unit has had to be installed at the equipment. These protection units are very expensive, costing in the order of USD 150 for a 10 pair (telecommunication line) unit. Single pair units can cost as little as USD 15. Note that it is essential that this protection unit has a fully bonded earth between the telecommunication port protection and the power line protection. Not all units have this equipotential bond.

II.3.3.3 Australian example of an earth voltage drop problem at a telecommunication centre

Telstra has experienced damage to equipment installed in a telecommunication centre and protected by primary protection. Investigation of the problem showed that a breakdown was occurring between the wiring from the MDF and the chassis of the equipment. The breakdown voltage between the wire and the chassis was approximately 1.5 kV for a 10/700 μ s waveshape. This proves conclusively that earth voltage drops of 1.5 kV and greater can occur in practice. Rather than change the earth wiring in the exchange, different equipment was used to perform the function. These exchanges are earthed in accordance with [ITU-T K.27] and the equipment is in an IBN. There needs to be a balanced approach between installation practices, resistibility of equipment and the addition of external protection.

II.3.3.4 Possible test for resistibility to earth voltage drop

As shown in clause II.3.2, the most significant voltage occurs when a single earth wire is used to connect the protection frame to the earth bar. Earth voltage drop is less of a problem across the protection frame due to the parallel down conductors in the frame, and is also less of a problem when multiple earth wires are used to connect the frame to the earth bar.

This test is not applicable if one or more of the following occurs:

- The equipment earth reference conductor is connected to the base of the protection frame.
- Shielded cables are used between the protection frame and the equipment.

- A mesh BN earthing system is used.
- The protection frame is directly connected to the CBN by short conductors (<1 m).

Table II.3-2 and the generator in Figure II.3-9 are based on the test surge 4, specified in Table 4-2 and clause 4.6.6 of [b-GR-1089]. The Telcordia test is widely used in North America. The Telcordia test has a maximum peak open circuit amplitude of 2.5 kV.

Table II.3-2 – Test voltage

Description	$U_{c(max)}$
Large external frame with a small number of down conductors or long earth wire (<10 m) in a building or large shelter	2.5 kV
External frame in a cabinet with a medium length single earth wire (<3 m)	1.5 kV
Small external frame with a short earth wire (<0.5 m)	Test not required. The voltage at the input of the equipment is assumed to be less than that which occurs for tests 2.1 and 2.2 in Table 2a of the applicable resistibility Recommendation (e.g., [ITU-T K.20], [ITU-T K.21] or [ITU-T K.45]).

The approximate surge voltage generated by a surge current being conducted in a bond wire is shown in Figure II.3-8.

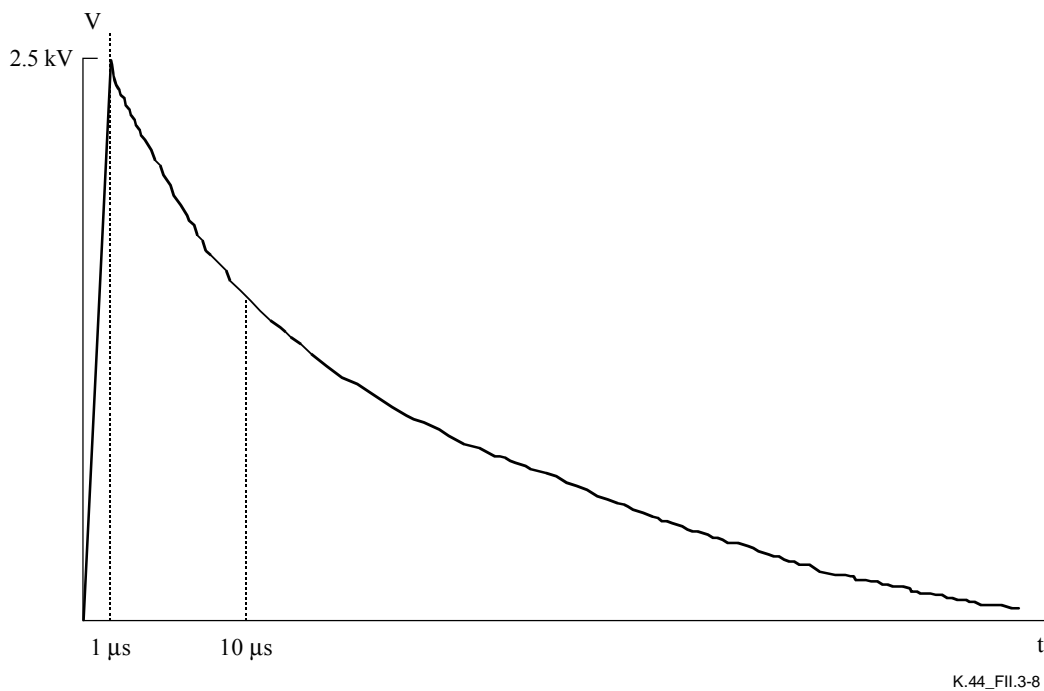
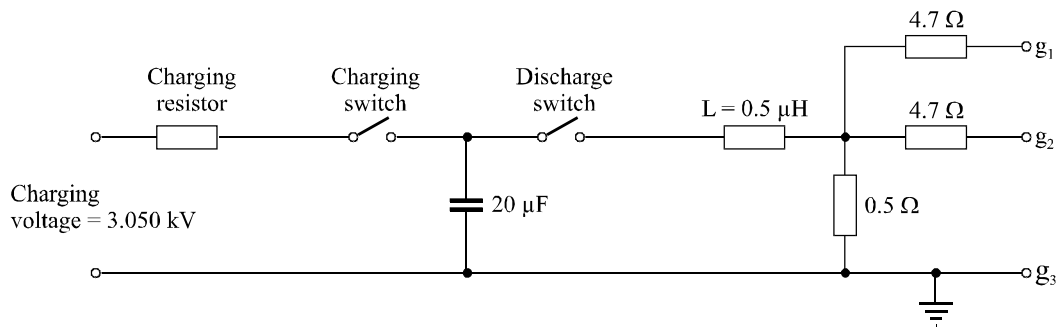


Figure II.3-8 – Earth voltage drop

The circuit in Figure II.3-9 produces a 2/10 μs waveshape and may be used to reproduce this effect. An approximate magnitude of the voltage which may occur is given in Table II.3-3.



L is small and mostly parasitic inductance of the wiring, may need to be adjusted to give the required front time of 2 μ s. Charging voltage is adjusted to give required o/c output voltage.

K.44(08)_FII.3-9

Figure II.3-9 – 2/10 μ s current surge generator

Table II.3-3 – Earth voltage drop test

Test No.	Test description	Test circuit	Test level	Number of tests	Agreed primary protection	Acceptance criteria	Comments
1.1	Earth wire voltage drop	Figures II.3-9 and A.5-1	See Table II.3-2	5	5 of each polarity	A	Applies only to equipment where there is a large protection frame and/or a single earth wire between the primary protection and the common earth point.

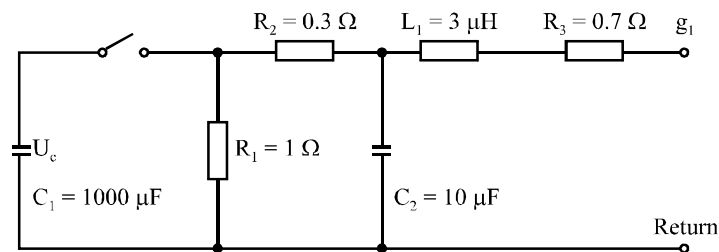
II.4 Current test on mains ports

When lightning strikes a building or shelter housing telecommunication equipment, the current waveshape is considerably longer than the 8/20 μ s waveshape traditionally used to test mains ports. Studies in Germany have shown that the current waveshape involved in a direct strike can have a 1/2 value of up to 350 μ s. An example in [b-ITU-T Handbook] shows that mains power line surges can have long tails. Tests on switch-mode power supplies have shown that a 350 μ s tail can cause damage, whereas a 20 μ s tail does not. There is no paper documenting this damage. It was, therefore, proposed that a 10/350 μ s be used to check coordination of primary protection with the equipment being tested. While this has been discussed in ITU-T, agreement for this test could not be obtained. This test remains under study. The coordination test in the product Recommendations requires an 8/20 μ s waveshape.

The proposed test is shown in Table II.4-1.

Table II.4-1 – Coordination test for mains ports to simulate a direct strike to the building or shelter

Test no.	Test description	Test circuit	Test level	Number of tests	Agreed primary protector	Acceptance criteria
1.x.a	Direct lightning mains port coordination L-N	Figures II.4-1 and A.6.4-1	$I_{(max)} = 10 \text{ kA}$ $R = 0 \ \Omega$	5 of each polarity	Agreed primary protector (mains)	A Note, a switching protector must operate at $I_{(max)}$
1.x.b	Direct lightning mains port coordination L+N-E	Figures II.4-1 and A.6.4-2	$I_{(max (L+N))} = 10 \text{ kA}$ $R = 0 \ \Omega$	5 of each polarity	Agreed primary protector (mains)	A Note, a switching protector must operate at $I_{(max)}$



NOTE – L_1 may need to be adjusted to give the correct rise time.

K.44(08)_FII.4-1

Figure II.4-1 – 10/350 μ s current surge generator

II.5 Earth and neutral potential rise

II.5.1 Background

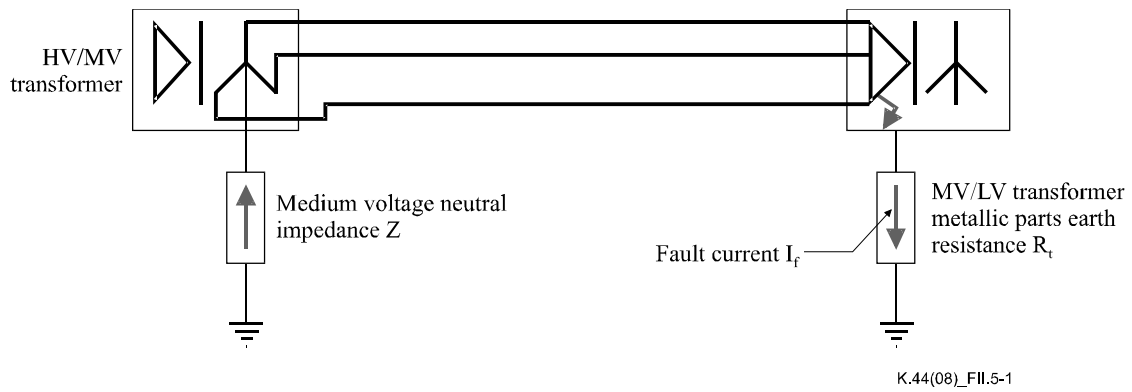
Depending on low voltage public distribution network design, some risks such as neutral potential rise and lightning surge transfer may occur on low voltage power plant.

II.5.2 Explanation

Earth and neutral potential rise happens mainly when the MV/LV transformer insulation is broken, or spark gaps operate to prevent transformer destruction by a lightning induction or direct strike to the line. An important 50 Hz current flows and the earth potential rises.

II.5.2.1 Earth potential rise

The first point is to understand the way to limit earth potential rise (EPR) when a fault occurs on the power plant. See Figure II.5-1.



K.44(08)_FII.5-1

Figure II.5-1 – Factors affecting the fault current

The worst-case fault current I_f is obtained when neglecting HV line impedance and coupling between the transformer's metallic parts earth and other earthing systems as neutral earth.

$$I_f = U / \sqrt{3 \cdot (Z + R_t)}$$

where U is the voltage between medium voltage active conductors.

The rise of earth potential at the MV/LV transformer is $EPR = R_t \cdot I_f$ (LV = low voltage).

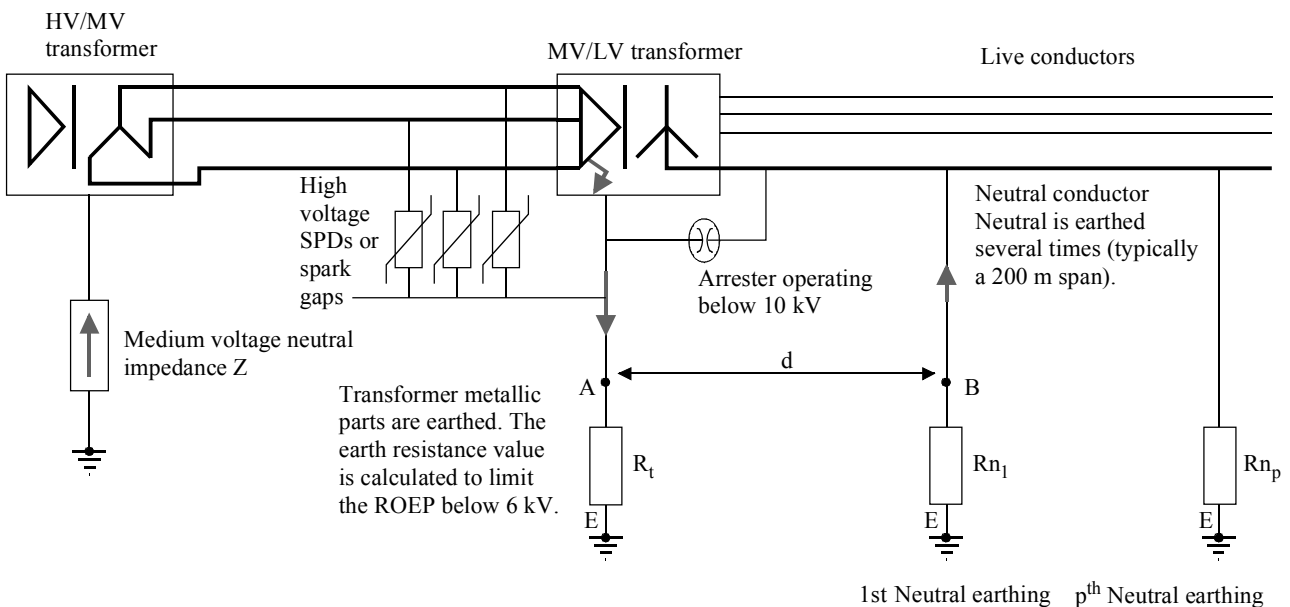
In France, this EPR value is limited to 6 kV.

II.5.2.2 Neutral potential rise

II.5.2.2.1 Coupling between transformer and neutral earth systems

Because of the design of neutral earthing, neutral potential rises by conductive coupling when medium voltage is connected accidentally to ground.

National regulations may fix limits for this rise of neutral potential (for example, 1500 V in France). See Figures II.5-2 and II.5-3.



K.44_FII.5-2

Figure II.5-2 – Coupling into LV neutral

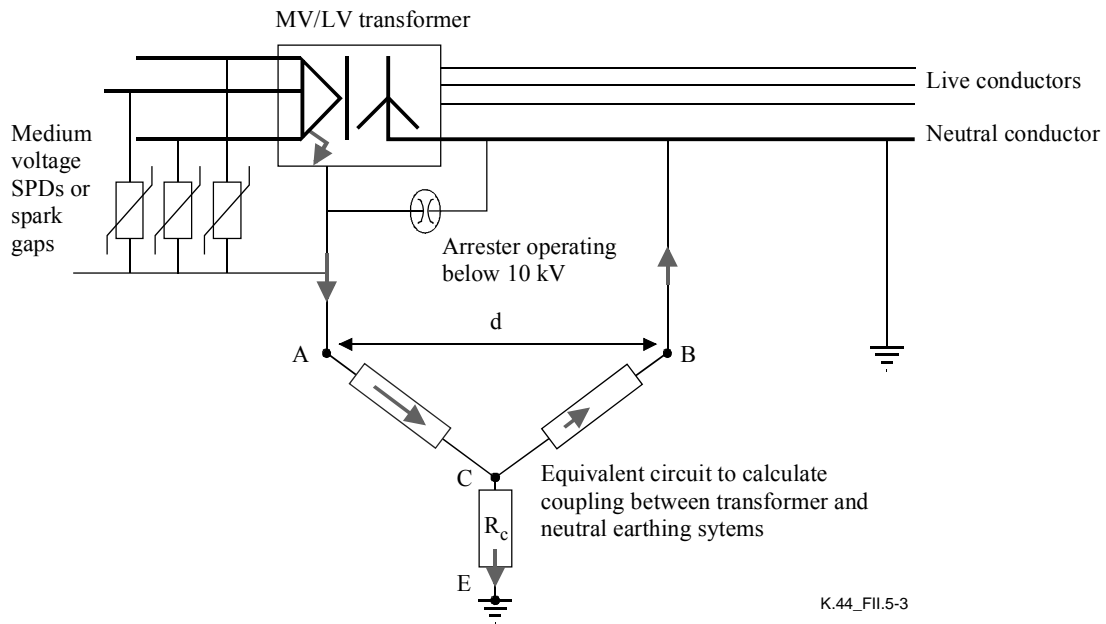


Figure II.5-3 – Limiting EPR by earthing design

The coupling resistance $R_c = \rho \cdot I / 2 \cdot \pi \cdot d$ is adjusted by varying d to obtain a rise of neutral potential below 1500 V or a coupling ratio (V_{AE}/V_{BE}) below 15% when a fault occurs.

When the soil has a high resistivity, the calculated resistance values may sometimes not be achieved and the rise of earth potential may be higher than 1500 V.

II.5.2.3 Currents that may flow through equipment

See Figure II.5-4.

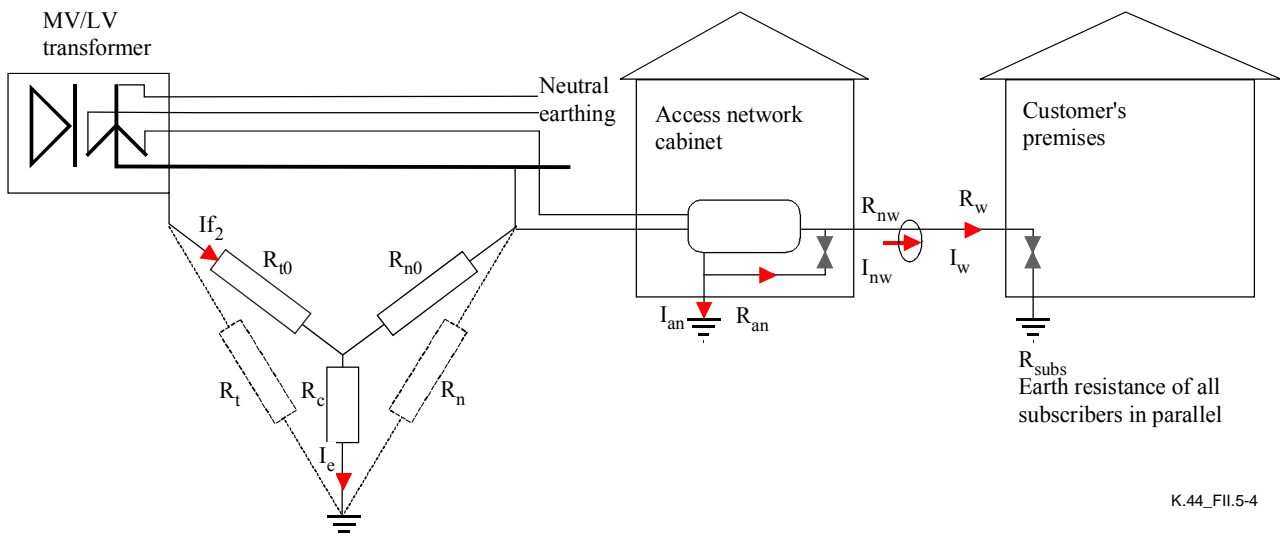


Figure II.5-4 – Mechanism of current flow through equipment

The results of the calculation when it is assumed that:

- 28 customers are connected with the same symmetric pairs (length 5 km, wire diameter 0.4 mm);

- the equivalent resistance of all their earthing systems in parallel is 2Ω ;
- the access network cabinet earth resistance is 50Ω ;
- the power system characteristics are $Z = j40 \Omega$, $R_t = 30 \Omega$, $R_n = 15 \Omega$, $d = 8 \text{ m}$;
- the soil resistivity is $300 \Omega \cdot \text{m}$;

show that tens of amps may flow through the equipment (disruptive discharge between mains port and equipment earth) to the access network cabinet earthing system.

Current may also flow either directly by telecommunication line SPDs (if they are installed, and in case of disruptive discharge between mains port and equipment earth) or through the equipment (disruptive discharge between the mains and telecommunication external ports) to the customer premises, I_w is about 1 A.

Note that the calculation is based on the same principle when replacing in Figure II.5-4 the customer premises by a telecommunication centre, or the access network cabinet by the customer premises.

II.5.2.4 Surge transfer

The lightning induced or direct surges transfer from medium voltage to low voltage may occur mainly if:

- 1) the transformer insulation breakdown is prevented by bypassing it with an arrester;
- 2) the transformer insulation between medium and low voltage windings is broken.

See Figure II.5-5.

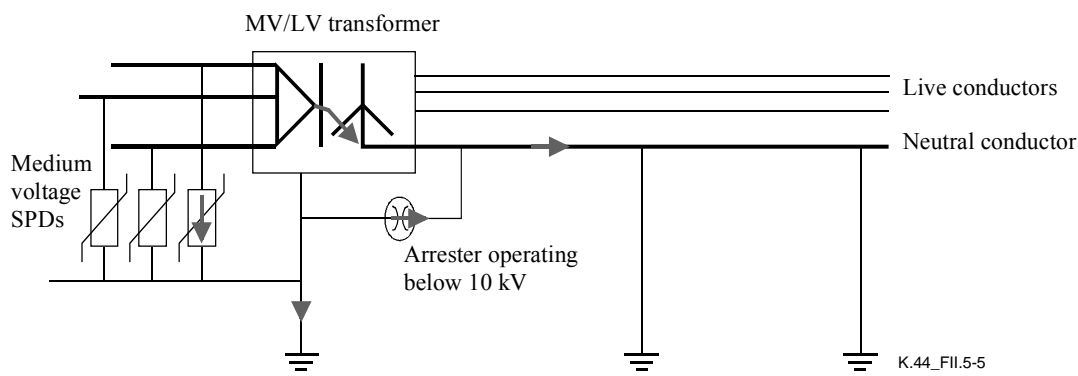


Figure II.5-5 – Transfer of overvoltage on to neutral

The surge will be followed by a significant 50 Hz current in case 1 when spark gaps are used, and always in case 2.

II.6 Special resistibility requirements

As mentioned in clause 5 "special" resistibility requirements may be required when mains SPDs cannot be installed or bonding between the mains and telecommunications cannot be achieved. Issues related to lack of bonding or long bond wires are discussed in [b-ITU-T K.66].

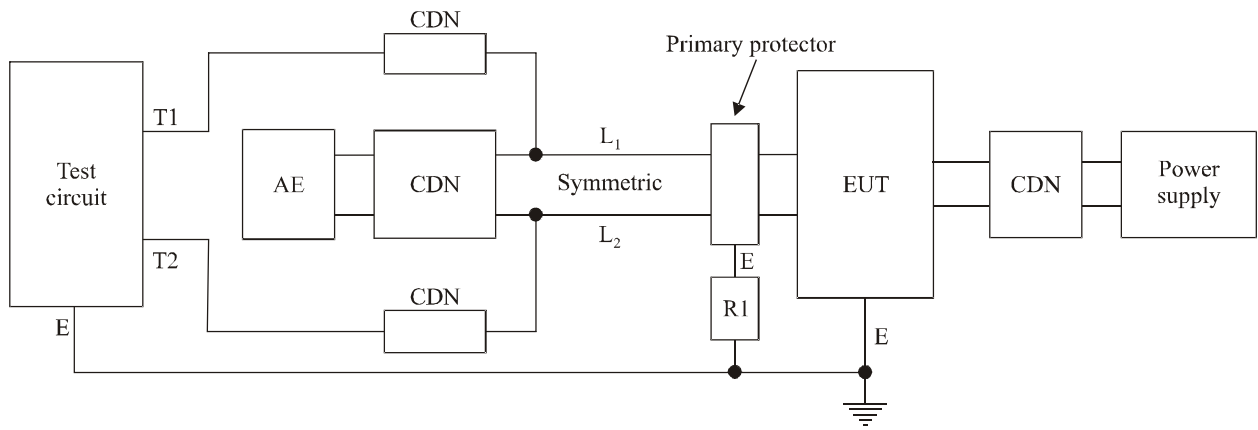
In some cases, bonding to the power system earth is not possible. Table II.6-1 provides special requirements that have been used to ensure safety and resistibility when bonding cannot be achieved.

Table II.6-1 – Resistibility and safety requirements of customer premises equipment powered by mains power

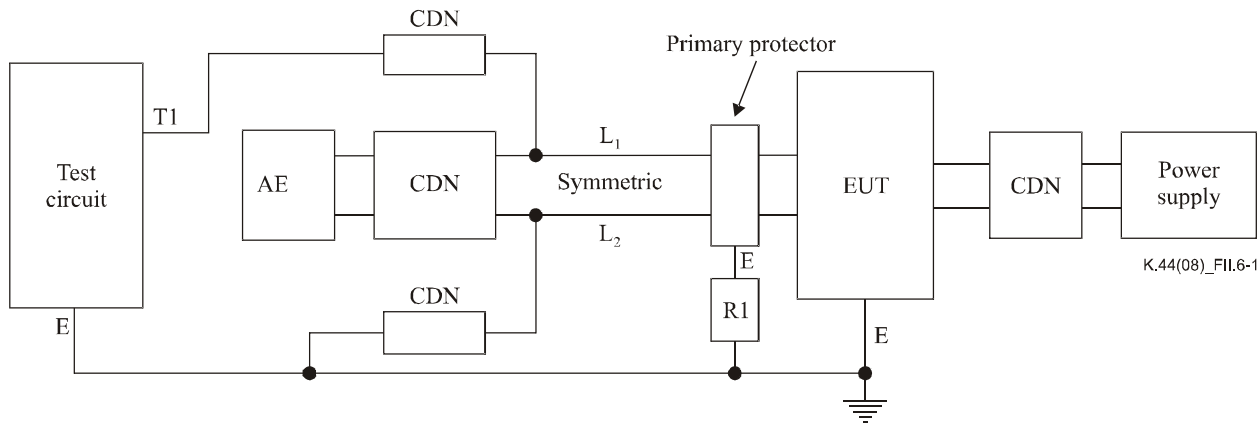
TEST		Power induction test	Power contact test	Lightning surge test	
Test level Wave shape or time	Test ports	Telecommunication line longitudinal	430 V _{rms} 0.1 s or 650 V _{rms} 0.06 s	230 V _{rms} 15 minutes [ITU-T K.21]	13 kV 10/700 [ITU-T K.21]
		Telecommunication line transverse	430 V _{rms} 0.1 s or 650 V _{rms} 0.06 s	230 V _{rms} 15 minutes [ITU-T K.21]	4 kV 10/700 [ITU-T K.21]
		Mains power longitudinal			10 kV combination [ITU-T K.21]
		Mains power transverse			10 kV combination [ITU-T K.21]
		Telecommunication line – Internal port			13 kV 10/700 [ITU-T K.21]
		Mains power – Internal port			10 kV combination [ITU-T K.21]
		Telecommunication line – Mains power line			13 kV 10/700 [ITU-T K.21]
					10 kV combination [ITU-T K.21]
		Internal line longitudinal			Under study [ITU-T K.21]
		Internal line transverse			Under study [ITU-T K.21]
Criteria		A	A (R, 160-600 Ω) B (R < 160 and R > 600 Ω)	A	

To ensure the safety of the customer, the equipment shall contain port to port isolation as given in the table.

The telecommunication line port is tested with primary protector and earth resistance when the equipment is designed to be always used with primary protection.



a) Longitudinal



b) Transverse

Figure II.6-1 – Testing for symmetric port R1: An earth resistance for a primary protector

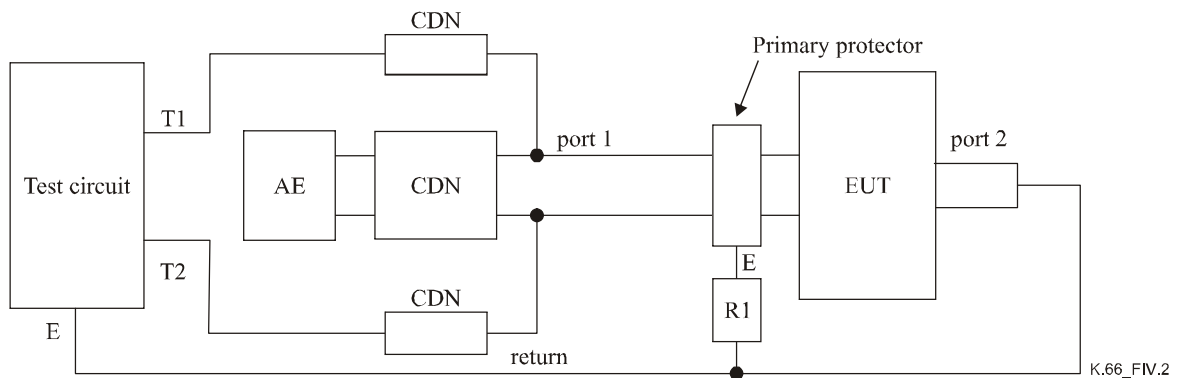


Figure II.6-2 – Testing between ports R1: An earth resistance for a primary protector

II.7 Equipment fire in equipment complying with [ITU-T K.21]

A network operator has experienced a problem with a fire occurring in equipment which complies with [ITU-T K.21]. The problem was able to be reproduced by performing the power contact test on a sample which had been subjected to the power induction test. It was subsequently found that the power induction test was damaging the PTC but not sufficiently to show up in the functional tests.

To test for this effect, it is suggested that test 2.3.1a (4.3.1a) of [ITU-T K.21], using the 20 Ω test resistor, be applied to a port which has previously undergone the power induction inherent test.

Bibliography

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- [b-ITU-T K.35] Recommendation ITU-T K.35 (1996), *Bonding configurations and earthing at remote electronic sites.*
- [b-ITU-T K.46] Recommendation ITU-T K.46 (2008), *Protection of telecommunication lines using metallic symmetric conductors against lightning-induced surges.*
- [b-ITU-T K.50] Recommendation ITU-T K.50 (2000), *Safe limits of operating voltages and currents for telecommunication systems powered over the network.*
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